GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE　Editor, JOHN R. HEWETT　Associate Editor, E. C. SANDERS

Subscription Rates: United States and Mexico, $3.00 per year; Canada, $3.25 per year; Foreign, $3.50 per year; payable in advance. ***Library and Student Rates:*** United States and Mexico, $2.00 per year; Canada, $2.25 per year; Foreign, $2.50 per year; payable in advance.

Remit by post-office or express money order, bank check, or draft, made payable to the *General Electric Review*, Schenectady, N. Y.

Advertising forms close on the first day of the month preceding date of issue.

Entered as second-class matter, March 26, 1912, at the post office at Schenectady, N. Y., under the Act of March, 1879.

Vol. XXVII, No. 3　*Copyright 1924 by General Electric Company*　MARCH, 1924

CONTENTS

PAGE

Frontispiece: Antenna and Power House of KGO 138

Editorial: Broadcasting 139

The Light of Knowledge and the Knowledge of Light 141
By L. A. HAWKINS

High Speed Passenger Locomotive for Paris-Orleans Railway 146
By W. D. BEARCE

Radio Broadcasting Station KGO 151
By ADAM STEIN, JR.

The Belt Driven Edison Bipolar Dynamos 163
By W. S. ANDREWS

Shaft Whipping 169
By DR. B. L. NEWKIRK

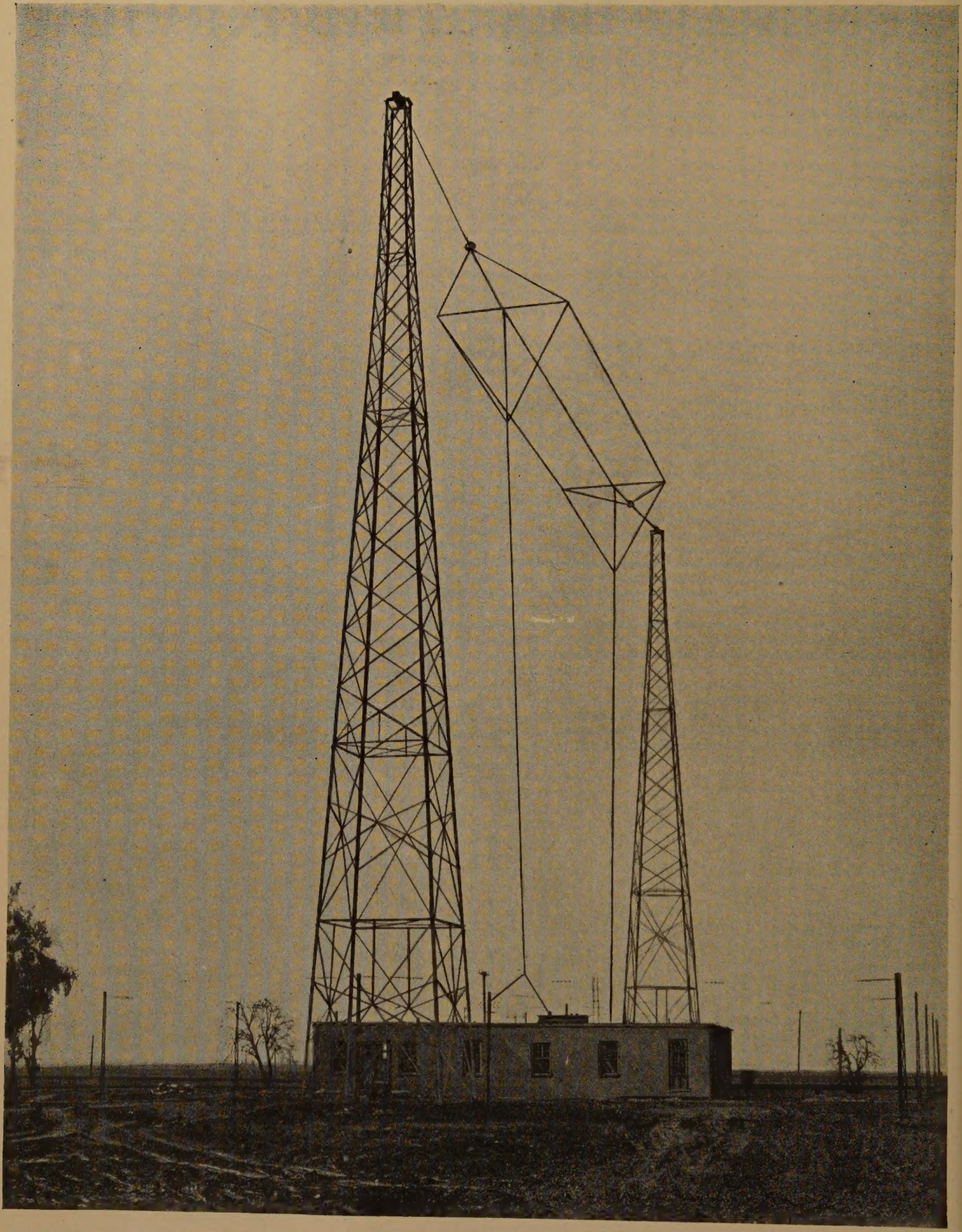
Otheograph Records of Steam and Electric Locomotives 179
By P. M. GILLILAN

The Electrically Operated Flow Meter 182
By R. E. WOOLLEY

Shaft Currents in Electric Machines 188
By P. L. ALGER and H. W. SAMSON

Studies in the Projection of Light. Part IX 199
By FRANK BENFORD

Library Section 208



KGO (Sister Broadcasting Station of WGY) is Located at Oakland, California, and was Placed in Regular Operation Last January. This photograph shows the power house, antenna, and counterpoise. Photographs of the studio building and radio equipment are shown in the article beginning on page 151

GENERAL ELECTRIC REVIEW

BROADCASTING

The opening of KGO, the new General Electric Broadcasting Station, located at Oakland, California, is of more than passing interest. We publish a description of this station and its equipment in our present issue.

This new station, together with WGY at Schenectady, and another that it is planned to build in Denver, Colorado, will provide most useful, interesting and complete facilities for broadcasting.

Beyond bringing every corner of the Union within earshot of their messages and music, they will spread their stories and news to both our northern and southern neighbors; the ships on, and the islands in, many seas and oceans will be within their range and the broad continents of the earth beyond the limits of these oceans will often pick up the tidings they broadcast.

In the past we have often sighed for a Bobbie Burns to sing the praise of steam, but in the present how much greater is our wish, and need, for a pen to write our newer story in the language of the people? We need a pen that can Out-Kipling Kipling in writing the story of the modern miracles that science has wrought, and is working, in this material (?) age of ours!

We think it was in 1911, before the days of broadcasting, that Rudyard Kipling wrote "The Secret of the Machine," and combined the wonders of wireless and the marine engine in just two verses.

"Would you call a friend from half across the world?
If you'll let us have his name and town and state,
You shall see and hear your crackling questions hurled
Across the arch of Heaven while you wait.
Has he answered? Does he need you at his side?
You can start this very evening if you choose,
And take the Western Ocean in the stride
Of thirty thousand horses and some screws!
The boat express is waiting at your command!
You will find the *Mauretania* at the quay,
Till the Captain turns the levers 'neath his hand,
And the monstrous nine-decked city goes to sea."

This was written in the infant days of the wireless telegraph before the wireless telephone had been born, and before modern broadcasting had been conceived. What we want is someone who can tell the man-in-the-street the story of modern broadcasting—to tell how the dwellers in crowded cities, the occupants of desert huts and lonely farms, the sick in bed, the mariner at sea, the lighthouse keeper, the lonely islander, those marooned in the frozen north, and in fact the great all, high and low, rich and poor, can have the common blessings, enjoyment, and education that modern broadcasting affords.

The story of how the constant and patient work of the scientist has gradually overcome all difficulties until this triumph was accomplished is well worth broadcasting.

* * * * *

Referring back to the verse we have quoted from Kipling—there is special interest in his lines:

"You shall see and hear your crackling questions hurled
Across the arch of Heaven while you wait."

This, of course, refers to the spark which was used to generate the damped waves used in earlier systems of wireless telegraphy. The wireless telephone was an impossibility until the invention of means to produce undamped waves.

Here it seems pertinent to point out that the development of the wireless art, both the telegraph and the telephone, has been accomplished purely by scientific work. There have been no chance discoveries such as have often aided other sciences.

Ever since those great pioneers in the art, Clerk Maxwell and Hertz, investigated the properties of electric currents and magnets and gave us the fundamentals of the greatest of all modern physical sciences—electromagnetic radiation—the art of wireless communication has advanced step by step.

Since this epoch-making work of Clerk Maxwell, which determined the fundamental phenomena taking place in the space surrounding electrified bodies, each advance has only been made by laborious experiments, patient research and costly developments.

The greatest of these advances has been the development of electric generators for producing electromagnet waves of radio frequency and the evolution of the many types of thermionic valves. It was these that made the wireless telephone and, therefore, modern broadcasting, a reality.

* * * * *

One of the most remarkable features of wireless broadcasting is that it has, by a single achievement, led to the elimination of man's greatest and most stubborn enemies in his fight to build up, first, a country wide and then a world wide civilization.

Civilization has only grown slowly as the means of communicating intelligence has been improved. Wireless has literally eliminated both distance and time as a stumbling block to the communication of intelligence between man and man. And broadcasting has put the advantages of this great achievement within the reach of all, or nearly all.

Today it is no idle boast to say that we have taken the blue of heaven's canopy for the roof of our auditorium and have chosen the peoples of the earth for our audience.

It seems almost like something superhuman to be able to fill the very space around the planet in which we live, and the space through which it moves, with any form of intelligence we wish. With the mundane, if useful, quotations of stocks and produce; the weather forecasts; news, national and international, elevating and degrading; literature in all its varying qualities; the dramatic art in any hue; poetry in all its many different shades of worthiness; and music great, good, bad and indifferent. We can put all these and more into space and any one with a suitable receiving set can listen to his choice.

The potential power of those who control what shall be radiated into space is enormous and their responsibility is equally great.

We cannot help wondering who in the future, five, ten, fifty and one hundred years hence, will be invested with this tremendous power and what use they will make of it.

The influence that good literature, beautiful poetry and great music (which has been called the universal language of mankind) can have on the development of the human intelligence, by stimulating the imagination and in inspiring the creative faculties, is so unthinkably great that it is no exaggeration to say that the future development of civilization must depend, in large measure, on how wisely or unwisely we use our new-born power. J. R. H.

ERRATUM

An error occurred in the contents page of our January issue which we wish to correct.

The two million volt lightning generator at the High Voltage Laboratory of the Pittsfield Works was credited to Dr. C. P. Steinmetz. The lightning generator originated with and was designed and built by the engineers of the High Voltage Laboratory at Pittsfield.

The Light of Knowledge and the Knowledge of Light

By L. A. Hawkins

Engineer, Research Laboratory, Schenectady, N. Y.

This is an attractively written article on some of the things we all want to know about. The infinitely large are interwoven with the infinitely small in a narrative of some of our scientific theories and achievements. This material was originally presented as a paper before the New York Section of the Illuminating Engineering Society at New York on December 13, 1923.—Editor.

In poetry and metaphor the word "light" has been used for thousands of years to signify knowledge or understanding. King David prays, "O send out thy light and thy truth." Omar Khayyam sings of "the one true light kindling to love." We have the same use in the idiomatic speech we hear daily, "To throw light on the subject," "to see the light," "an illuminating commentary," etc. "Enlighten," in its literal sense, is now obsolete; it has become synonymous with "instruct" or "inform." Of all metaphors there is none more natural. What light is to the eye, knowledge is to the mind. Darkness is dispelled, dimness becomes clarity, and the range of vision is increased. The metaphor is so natural that its significance is overlooked until it is forced on the attention in some striking way.

A few weeks ago I heard a lecture on some recent advances in astronomy. No one hearing that lecture could fail to be impressed by the utter dependence of astronomical science on the phenomena of light. I do not mean at all the phenomena of vision. I am not referring to the obvious fact that sight is the only one of the senses that is of any use in astronomy. I mean that the interpretation of astronomical observations is almost wholly dependent on our knowlege of optical phenomena as developed by physical science. For instance, through measurements of temperature and diameter of multitudinous stars, the astronomers have been able to determine to their satisfaction the life history of a star. While the masses of all stars are within fairly narrow limits, from about one-seventh to about thirty-three times the mass of our sun, the densities, that is the sizes, and the temperatures, vary over an enormous range. It seems that the stars begin as huge masses of low density, relatively cold and therefore red in color. These, of which Betelgeuse is an example, are called the red giants and have temperatures around 3000 deg. C. Gradually they contract, growing denser and hotter, becoming yellow giants, like Polaris, with temperatures around 6000 deg. and then, as they contract still further, some of them become white and blue white, like Rigel, with temperatures of nearly 20,000 deg. A few reach temperatures of about 25,000 deg. Then, though they still contract, the temperature falls, so we have the white dwarfs, like Sirius, then the smaller and yellow dwarfs like our sun, and finally, smallest of all, the little red dwarfs in the last stage of the progress toward extinction.

Now the data on temperature and size, which have made possible the tracing of stellar history, have come wholly through our knowledge of the phenomena of light. Three methods have been used for determining temperatures. Two of these depend solely on measurements of spectra, the third on a combination of photometry and a use of the principle of light interference. The size also is determined by spectroscopy and photometry, though by the use of different methods.

But this is not all. The distance of a star was formerly measured by determining the parallax, that is by triangulation, using the earth's orbit as the base line, but that method was applicable only to the nearer stars. But now, knowing the temperature and size of a given star and hence the total lumens, it is a matter of simple photometry to determine its distance, no matter how great. Thus modern astronomy is able to place accurately even the farthest stars, and thus completely to map the stellar universe and to determine its shape and dimensions. It is found that our stellar universe is shaped like a thin watch, with a diameter of about 35,000 light-years. Our solar system lies approximately in the central plane about half way between the center and the periphery. On a map of this plane about three feet in diameter, a circle not much more than an inch in diameter would enclose not only our solar system but all the stars we can see with the naked eye. And yet our knowledge of the principles of light enables us to explore the farthest edge of this gigantic universe of ours.

And even this is not all. When Columbus saw driftwood in the open sea, it told him of new land below the horizon. Just so the astronomers, looking beyond the limits of our stellar universe, see masses of matter in the nearly empty space, which tell them not only that our universe is moving edgewise through space but that there are almost certainly other universes, many or few, large or small, inconceivably remote, but yet sending us this driftwood to tell us of their existence. Some of these strays, called the globular masses, are drawn toward and into our universe at enormous velocity. Others, the spiral nebulae, are so tenuous that they are repelled by the pressure of light more strongly than they are attracted by gravity and so, when we pass near enough to them, are pushed back from our path. Some of these nebulae are of enormous dimensions, and are at distances inconceivably great, even in terms of the astronomer's gigantic measuring stick, the light-year.

It is a wonderful story that light tells us. Here we are on one of the smaller planets circling around a sun, itself a yellow dwarf among the thousands of stars we see above us on a clear night, and all those thousands are an insignificant part of the whole number and occupy an insignificant part of the whole space of our gigantic stellar universe, which itself in its movement through space is encountering other masses which tell of other universes so remote that they may forever remain unknown. It makes this earth on which the human race has fought and suffered and learned and loved for tens of thousands of years seem a trivial and transitory thing. And it is still more humiliating when the astronomers tell us that this earth of ours is as fortuitous as it is trivial. We are not, it seems, an offspring of the sun, flesh of its flesh, but merely part of the remains of some star that wandered too near the sun for its own good and was disrupted by the resulting forces. How fortuitous such an event must be is shown by the fact that twenty tennis balls, flying about in a space equal to that occupied by the earth, would represent the density of stars in our universe and would have the same likelihood of collision. But once in countless years such a collision or near collision occurs, and the one which has most interest for us apparently did occur a billion or so years ago. Part of the fragments of the unlucky stranger, caught in the sun's gravitational field, came together and formed this earth of ours, and, as it cooled and water condensed, life appeared, first in water and then on land, and, after another two or three hundred million years, man evolved, and after tens of thousands of years of living, fighting and dying like the other brutes, began to look about him and to question nature.

We do not know much about the speculations of early man, but more than two thousand years ago, in Greece, scientific thought began a vigorous development. The first elements of science were four in number, earth, air, water and fire. But two thousand years later, modern chemistry was born, and one after another the true elements were discovered, until we now have the complete periodic system of 92 elements, all but four or five of which are known. But even while the chemist has been completing his table of elements, the physicist has been resolving them all into an even simpler system than Aristotle's. We now know that every atom, whatever the chemist may call it, is made up of a combination of the two proto-elements, the positive nucleus and electrons. There are just two ways in which these proto-elements manifest themselves. First, as they are particles of electricity, they naturally manifest themselves as electric charges, producing when at rest electric stress, appearing as electromotive force in a condenser or as chemical affinity in a molecule, and in motion appearing as an electric current in a metallic conductor, in an electrolyte, or in vacuum. But these effects, except for chemical affinity, can be produced only by free electrons or by splitting electrons and positive nucleus apart, for while they remain together in an atom their electric charges neutralize each other at distances greater than that between atoms in a molecule. But there is another way in which, without separation, they may manifest themselves at distances of billions of billions of miles, that is, by the absorption or radiation of light. All that goes on in nature from the smallest atom to the edge of our mighty universe, and beyond that to the unknown universes of which the astronomer tells, all that goes on may be resolved into two classes of phenomena, those of electric charges and those of light, using the term light in the broad sense of radiant energy. Thus in one sense we simplify Aristotle's system of four elements to two. His earth, air, water and fire become electric charges, and light.

We have seen how essential is the knowledge of the phenomena of light in the astronomer's field, where the mile or kilometer is too pitifully small a unit to be of use and is discarded for the light-year. Now let us look at the other extreme, in that part of the physicist's field where the inch or centimeter is awkwardly gigantic. The Nobel prize in physics was awarded this year to Prof. Niels Bohr for his work on atomic structure and all physicists agree that the prize was richly deserved. Bohr's work was a marvelous combination of mathematical theory and experimental confirmation. His theoretical structure was founded on the earlier work of Planck and Rutherford. Physicists had found that in the field of radiant energy the classical mechanics gave results not according with experimental facts. To explain this discrepancy, Planck made the bold assumption that energy, like matter, is atomic, that energy can be absorbed or emitted only in multiples of a definite unit known as a quantum. The magnitude of this indivisible unit of energy varies, however, with the frequency of the light, being greater for high frequencies and lower for low frequency. Thus the quantum is expressed as a product, one factor of which is the constant h, now known as Planck's constant, and the other the frequency v, at which the energy is radiated or absorbed. This quantum theory not only resolved the apparent contradictions between experiment and previous theory, but pointed the way to new theory and experiment, of which Bohr's work has been the most brilliant example. Note again how fundamental in all this are the phenomena of light. Planck's atom of energy, or quantum, is the product of his constant by a frequency, and that frequency is the frequency of the light radiation involved; in other words, it is the speed of light divided by the wavelength on which the energy is being radiated or absorbed.

Rutherford had postulated an atomic structure consisting of a central positive nucleus and electrons revolving around it like planets around a sun. It had of course been assumed that radiation was the result of electron movement. The trouble was to explain why an electron in its orbit did not continuously radiate energy and run down, and why the radiation was in the form of monochromatic light as shown by the spectrum bands, instead of being in the form of a continuous spectrum. When an electric charge in motion is stopped, decelerated, or deflected, it radiates energy, and an electron in its orbit is an electric charge continuously undergoing deflection.

This was where Bohr started. He took a hydrogen atom, as the simplest, and assumed for it Rutherford's structure of a positive nucleus and an electron revolving around it in a circular orbit. He also assumed that similar relations hold, between the radius of the orbit, and the velocity and energy of the electron in that orbit, as in a system consisting of a sun and a planet moving in a circular orbit. This would make possible a continuous series of such orbits, the energy in the outer orbit being greatest and in the inner orbit least, but here Bohr brought in Planck's theory by assuming that not all these orbits are possible, but only those in which the angular momentum of the electron is a multiple of Planck's constant, h. The orbit nearest the nucleus has an angular momentum equal to $h/2\pi$, the next has twice this value, etc. This makes it possible to calculate the radius and energy of each orbit. He then made the final assumption that emission of light occurs when an electron shifts from an outer orbit to an inner one, that is from a higher to a lower energy level, and that the frequency of the emitted light is the difference in energy of the two orbits divided by Planck's constant. This gave the frequencies or wavelengths at which light could be radiated from a hydrogen atom, but this should be subject to confirmation by the hydrogen spectrum, for in that spectrum each line reveals a wavelength at which energy is actually radiated. He made the comparison, the observed lines coincided with those he had calculated, and the Bohr theory was firmly established. Bohr has extended his theory far beyond this and has adduced other experimental verification, but this is enough to bring out the point that the phenomena of light as displayed in the spectrum were as essential to Bohr in revealing the mechanism of the atom in radiation as they were to the astronomer in measuring the temperature of Betelgeuse and Rigel.

Again in mathematical or philosophical science the phenomena of light are fundamental. I am not of the alleged dozen who fully understand the theory of relativity, but I wish to point out in passing that Einstein establishes the relativity of everything else in the universe for the sake of maintaining the absolute fixity of just one thing; the velocity of light. Space becomes four dimensional, and is warped by the presence of matter, straight lines are bent back to their starting points, and seeming paradox heaped on paradox, all in order that the mathematical physicist may pin his faith and take his stand on the one unchanging and absolute verity, the propagation of light at 300,000,000 meters a second.

Many other examples could be cited of the part light is playing in the advancement of science. For instance, we can now determine the arrangement of atoms in crystalline material and measure the distances between them. Again it is a spectrum that reveals these new facts, but this time a spectrum of light rays of very short wave length, that is, X-rays. These short rays, passed through crystalline matter, produce spectra on a photographic film, just as the longer waves of visible light passed through a diffraction grating produce spectra by interference. These X-ray spectra, properly analyzed, show how the atoms of different materials are arranged. They show for instance why copper is more ductile than iron. It is because the atoms are so arranged that they can move relatively more readily without destroying the formation. When iron is heated red hot, its atoms slip over into an arrangement like that of copper and the other more ductile metals. So we see that theory as well as practice supports the blacksmith's custom of heating his iron for forging.

But enough has been said to bring out the new significance that the developments of modern science have revealed in the ancient metaphor which identifies light with knowledge. Let us now look at the converse of this relation. To what extent does our modern knowledge cover the phenomena of light in all its phases?

We know of course that visible light is only a narrow band in the great series of radiations, extending from the longest electric waves, through the thermal waves and visible spectrum, on through the ultra-violet, to the shortest known waves, the X-rays and the gamma rays from radium. We know the lengths of the waves of each type in the series. We have a fairly satisfactory picture of the mechanism by which each type of wave is produced. But when it comes to producing them at will there are enormous differences in the efficiencies of production. Electric waves are produced at reasonable efficiency. Thermal waves are produced all too easily. As a General Electric man, I was a bit chagrined at seeing this month in a General Electric advertisement devoted to heating units the statement made that the units were 100 per cent efficient, as though that were an achievement. The real problem is to prevent electrical devices intended for other uses from being merely heating units of 100 per cent efficiency. For instance, our most efficient incandescent lamps, our Mazda C lamps, are only about 3 or 4 per cent efficient in terms of the ideal light or about 7 per cent efficient in terms of visible radiant energy. All the rest of the energy, that is over 90 per cent, appears as heat. About the same efficiency represents the best we can do in the production of ultra-violet rays, while X-rays are produced at an efficiency of only about 0.2 per cent. As for the gamma rays of radium, while some day we shall probably be able to produce their equivalent, when we learn how to build X-ray tubes to operate on one or two million volts, we cannot today produce them at will at all. We can only take them at the rate radium gives them to us, and nothing we can do, with heat or cold, or any other agency at our disposal, suffices either to increase or to diminish the yield.

Why is it that, knowing as much as we do about light, knowing so much about it that we find in our knowledge the key to so many and so diverse scientific problems, we are unable to produce that well known thing with an efficiency better than a beggarly three or four per cent?

In part, it is because of the inherent limitations imposed on us by materials. Most artificial light is today produced by incandescent bodies. By forcing a high current through a small wire we set the atoms and free electrons of the metal into vibrations which produce radiations of corresponding frequency, and if we force the rate of vibrations far enough we reach frequencies corresponding to visible light waves. If, for such a light emitting filament, we could plot the distribution of velocities of all the atoms and free electrons at any instant, we would find that we had all velocities from zero to maximum and that the distribution followed a probability curve, with its peak below the visible spectrum. By sending still more current through the filament, that is by heating it still more, the peak may be advanced a little toward the visible spectrum, but we cannot go far in this direction without burning out the filament. The maximum temperature we can reach is fixed by the melting point of the metal. Practically we are held to a considerably lower temperature by the vaporization of the metal, which, well below the melting point, becomes so rapid as to make the life of the filament uneconomically short. Evaporation seems to be a characteristic phenomenon inherent in all metals at high temperature, as definite a thing as light radiation itself, and to put definite limits to the efficiencies obtainable from incandescent bodies. When we have selected as filament material tungsten, having the lowest rate of vaporization of all metals, and when we have minimized that vaporization as far as possible by surrounding the filament by an atmosphere of inert gas, we have gone about as far as we can on the road to incandescent efficiency, and we see no way over, around, or through, the barrier that forbids our further progress, the barrier formed by the inherent characteristics of materials.

But there are other means than incandescence for producing light. In accordance with Bohr's theory, when an electron is shifted from one orbit to another a quantum of light of a definite wave length, that is, a quantum of monochromatic light, is radiated. If it were possible to apply energy to the molecules of a gas in such a way that it would all be effective in displacing electrons from their orbits, all that energy would be returned in the form of light as the electrons returned to their normal orbits, provided the gas were such that the frequency of those orbits corresponded to wavelengths in the visible spectrum. In that case we would be producing light with 100 per cent efficiency. Efficiencies several fold that of our best commercial lamps have been produced in this way in the laboratory, but the light was too feeble to be useful. How far we may be able to go in this direction it is impossible to predict. Electrons in the molecules of a gas may be displaced from their orbits by the passage of an electric current. In this manner electrons may merely be shifted from one orbit to another, in which case the molecule is said to be excited; or, by a higher voltage, the electron may be torn completely away from its positive nucleus, in which case the gas is said to be ionized. In the excited molecule the return of the electron to its normal orbit produces light corresponding to a single line in the spectrum, while in ionized gas the recombination of an electron and positive ion produces the entire spectrum. But the production of these effects is accompanied by losses, which with our present knowledge cannot be avoided and which result in a low over-all efficiency. There are losses in passing the current through the gas, for the passage of current means the production of free electrons and the acceleration of electrons and ions. The production of electrons takes energy, as for filament excitation when a hot cathode is used as the source, and there are limitations as in the space charge effect, that is the mutual repulsion of electrons, which limits the current and increases the voltage drop at the cathode, while if the voltage is raised so as to produce ionization and to neutralize the space charge effect by the presence of positive ions, other losses are introduced, since not all the wavelengths at which energy is radiated are in the visible spectrum, and there are thermal losses from the acceleration of the ions by the electric field. How far these present limitations on efficiency are inherent cannot be definitely determined with our present knowledge. New possibilities have been opened up by the discovery that excited molecules of one gas may transfer their energy to, and thereby excite, the molecules of a second gas mixed with the first. For instance, mercury vapor may be excited by subjecting it to monochromatic ultra-violet light of wavelength corresponding to one of the lines of the mercury spectrum, and mercury vapor so excited will emit the characteristic mercury spectrum. The same light has no effect on thallium vapor. But if now both vapors are present in a tube subjected to that light, the radiation from the tube will be a combination of the mercury and thallium spectra. By such combinations the possibilities are increased of higher efficiency in light production. One gas may prove capable of excitation with relatively low losses, but its characteristic radiations may not occupy effective places in the spectrum. A second gas may be difficult to excite, but as a light radiator it may be highly efficient. By mixing the two gases it may be possible to excite the first, and let it excite the second, thereby securing the more effective radiations with low exciting losses.

There are still remaining the possibilities of fluorescence and phosphorescence. Fluorescence is a phenomenon resulting from the ability of certain substances to act as frequency changers of radiation. For instance, some salts exposed to ultra-violet light absorb the short waves and transform the energy to longer waves, so that they glow with light. If some such substance could be found which could efficiently convert to light some form of energy which can be efficiently produced, we should have a truly efficient light source. But no such substance, nor an approximation to it, is known. Such fluorescence as we can now produce is feeble and inefficient.

The type of phosphorescence illustrated by the firefly, with its luminous efficiency of about 90 per cent, has long been a fascinating subject for speculation and experiment. It is the production of so-called cold light by chemical reaction at low temperature. It has been determined that the firefly's phosphorescence is the result of an oxidation process, the elements of which have been isolated and named luciferin and luciferase. Similar heatless combustion has been obtained in laboratory experiments using potato juice and pyrogallic acid as the elements, but the resulting light was very feeble. Possibly further work may show how brighter light may be obtained, but it is altogether likely that the elements of this heatless combustion may be too costly to be economical. The firefly has the advantage that it can use the fuel over and over again, for in its system the products of combustion are reduced so that the original elements are renewed. It is a cyclic process, somewhat similar to the oxidation of hemoglobin in our lungs and its partial reduction in our circulatory tract. Unless we can duplicate the firefly's performance with cheap materials, or unless the products of combustion can be cheaply restored to their original condition, both of which assumptions are improbable, we shall still be forced to seek our commercial light elsewhere.

But it is almost certain that the truly efficient light source, when it is found, will operate by the displacement of electrons, not by the agitation of whole atoms which we call incandescence. The displacement of the electrons may be by excitation of gas molecules as in the low pressure glow lamp, by ionization as in the arc, by some transformation of radiant energy as in fluorescence, or by low temperature chemical reaction as in the phosphorescence of the firefly, but one thing is sure, however difficult the progress, and however unpromising the present prospects, science will never rest content with a maximum efficiency of a few per cent in an energy transformation so vital to health, wealth and happiness as is the production of light.

High Speed Passenger Locomotive for Paris-Orleans Railway

By W. D. Bearce

Railway Engineering Department, General Electric Company

In our February issue we mentioned the Paris-Orleans electric locomotive in connection with the "Erie Tests." The present article describes this locomotive in considerable detail.—Editor.

The recent successful demonstration of the Paris-Orleans gearless passenger locomotive recalls the fact that the original electrification in this country, that of the Baltimore and Ohio Railroad, started operation with gearless locomotives in 1894. This type of locomotive used a four-pole motor, the armature of which was mounted directly on the main driving axle and was connected to the driving wheel through a spider and rubber driving cushions. This was essentially a quill drive.

In 1904 when orders had been placed for high speed passenger locomotives for the New York Central Railroad, the gearless motor was again used; this time the bipolar type was mounted directly on the driving wheel without quills. There are now 73 high speed passenger locomotives in operation on the New York Central Railroad using the bipolar gearless motor. These locomotives were guaranteed to operate successfully at 75 miles per hour and were tested up to 85 and 90 miles.

In 1918 locomotives were furnished to the Chicago, Milwaukee and St. Paul Railway for high speed passenger service using this same type of motor. It is, therefore, quite natural that the designers should select a locomotive of this design to fulfill the requirements of the Paris-Orleans Railway for a locomotive having good riding characteristics at over 80 miles per hour.

The outstanding characteristic of this locomotive is its freedom from any tendency toward periodic vibration throughout its entire range of speed. The high speed running qualities are due not only to the use of the gearless motor, but to special designs used in the leading and trailing trucks. The roller centering device, which is used to eliminate the periodic oscillations which develop in most types of running gear, has demonstrated its ability to insure safe operation at practically any reasonable speed.

The running gear of the locomotive has two 3-axle driving trucks and a 2-axle guiding truck at each end. The control and auxiliary equipment is carried in two box cabs, each of which is attached rigidly to the driving truck. The 3-axle driving trucks are connected by an articulated joint and each guiding truck is articulated at its inner end to the main truck. At its outer end, the cab is supported on two rollers which rest on inclined planes mounted on the truck near the draw bar. Any lateral motion of the truck causes the rollers to move up one or the other of the inclined surfaces, thus lifting the weight of the cab and transferring this weight to the rail against which the pressure is being exerted. As the roller returns to its normal position, there is no tendency for the cab to pass beyond the center point, thus avoiding the tendency to oscillation.

The motor fields and frames are constructed to form an integral part of the truck frame and running gear, and the armatures are mounted directly on the driving axles. Current is collected from an overhead trolley approximately 20 feet above the rail by means of the usual sliding pantograph, one of which is mounted on each cab. The principal weights, ratings and dimensions are given in Table I.

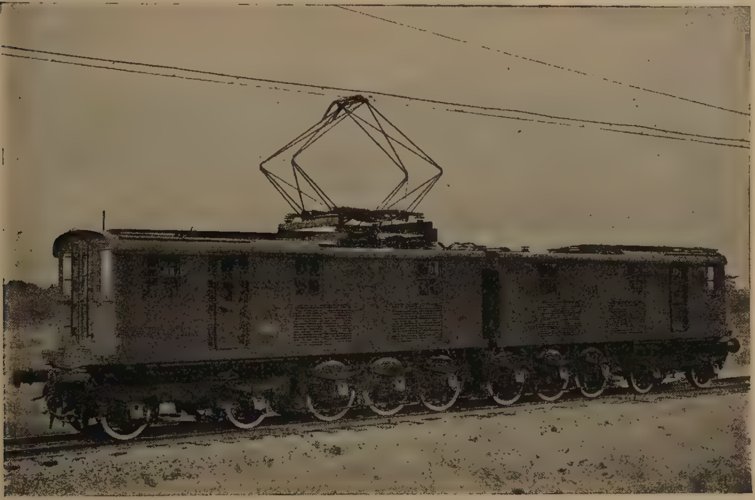


Fig. 1. High-speed Gearless 120-ton Passenger Locomotive Built for the 1500-volt Direct-current Electrification of the Paris-Orleans Railway in France

Tests

In order to determine definitely the riding qualities of this locomotive, a large number of runs were made over the test tracks at Erie operating at speeds between 100 and 130 km. (80.8 miles) per hour and over. On several trips, speeds of 159 km. (99 miles) per hour were reached, and on December 2nd a maximum figure of 105 miles per hour was attained. The locomotive operated very successfully at these high speeds and there was no indication of periodical oscillation or nosing. The tests included critical observation of both the front and rear of the locomotive, and there was no apparent tendency toward any objectionable movements, which might have injurious effect upon the track. Records were also obtained by means of the Otheograph, which

TABLE I

WEIGHTS, RATINGS AND DIMENSIONS OF PARIS-ORLEANS LOCOMOTIVE

ELECTRICAL DATA

Nominal voltage of system	1500 volts d-c.
Average line voltage assumed	1350 volts

	One Hour Blown	*Continuous*
Rated tractive effort (1350 volt)	8460 kg. (18,650 lb.)	5700 kg. (12,600 lb.)
Speed at rating (1350 volt)	90 km. p. h. (55.9 m.p.h)	101 km. p.h. (62.8 m.p.h.)
* Total horse power	2820	2130
No. of motors	6	
Type of motors	GE-101-A	
Voltage of motors	675	675
Tractive effort at 30 per cent tractive coefficient		23000 kg. (50700 lb).

MECHANICAL DATA

Track gauge	1.45 m. (4 ft. 9 in.)
Diameter of drivers	1200 mm. (47.2 in.)
No. of driving axles	6
Diameter of guiding wheels	915 mm. (36 in.)
Number of guiding wheels	8
Total wheel base	16.32 m. (53 ft. 6 in.)
Max. rigid wheel base	2.85 m. (9 ft. 3½ in.)
Width overall	2.93 m. (9 ft. 6 in.)
Length over buffers	19.02 m. (62 ft. 0 in.)
Height over trolley locked down	3.84 m. (12 ft. 6 in.)

SCALE WEIGHTS

On drivers	76,600 kg. (169,000 lb.)
Per driving axle	12,770 kg. (28,170 lb.)
Dead weight per driving axle	4,120 kg. (9,064 lb.)
On guiding axles	32,200 kg. (71,000 lb.)
Per guiding axle	8,050 kg. (17,750 lb.)
Elec. and air brake equipment	46,800 kg. (103,000 lb.)
Mechanical equipment	62,200 kg. (137,000 lb.)
Total weight	108,800 kg. (240,000 lb.)

*French horse power = 736 watts

indicate unusual freedom from nosing at high speeds. Examinations of the track after these runs were made showed complete absence of any detrimental effects.

The commutation of the motors was observed under all operating conditions and reported to be excellent. Other tests included commutation tests with rapidly changing trolley voltage and wheel slipping with and without sand.

Mechanical Construction

Each main driving truck consists of three axles, each carrying the armature of the bipolar gearless motor mounted on wheels 1200 mm. (47.2 in.) in diameter. This truck has a maximum rigid wheel base of 2.85 meters (9 ft. 3½ in.). The truck frame consists of two steel plate side frames securely bolted to two end transoms and two intermediate transoms. The journal boxes are carried in guides which permit them to move vertically, and are held in place by tie bars which can be removed to permit dropping the motor armatures and wheels into a pit. The body of the truck is so proportioned in conjunction with the platform and cab structure that it provides a suitable path for the magnetic flux of the motors. The journals are of the collarless type and the end thrust of the axle is taken up by a bronze and babbitt liner located on the outside of the wheel hub and running against a cast steel journal box.

The guiding trucks are also made up of steel plate side frames riveted and bolted to structural steel end frames and cross transoms. A longitudinal center member of structural steel supports a center plate for carrying a portion of the weight of the locomotive at the inner end of the truck. The outer end of this member carries the truck portion of the centering device, which forms a support for a portion of the weight of the superstructure. The journals are similar to those used on the main driving axles.

Superstructure

A platform built up of structural steel longitudinal and cross members is bolted to each driving truck and supported near its outer end by the roller centering device resting on the guiding truck.

Each cab is of the box type containing a compartment at the outer end for the operator and the remainder for housing the apparatus. The outer end of the cab is tapered to a width of 2.63 meters (8 ft. 7½ in.) in order to conform to the specified clearance lines when passing around a curve as small as 80 meters (260 ft.) radius. The operator's compartment is 1.5 meters (4 ft. 11 in.) long with a corridor extending back on each side to an outside door and to a door opening into the apparatus compartment. A door is also located in the front end of each cab.

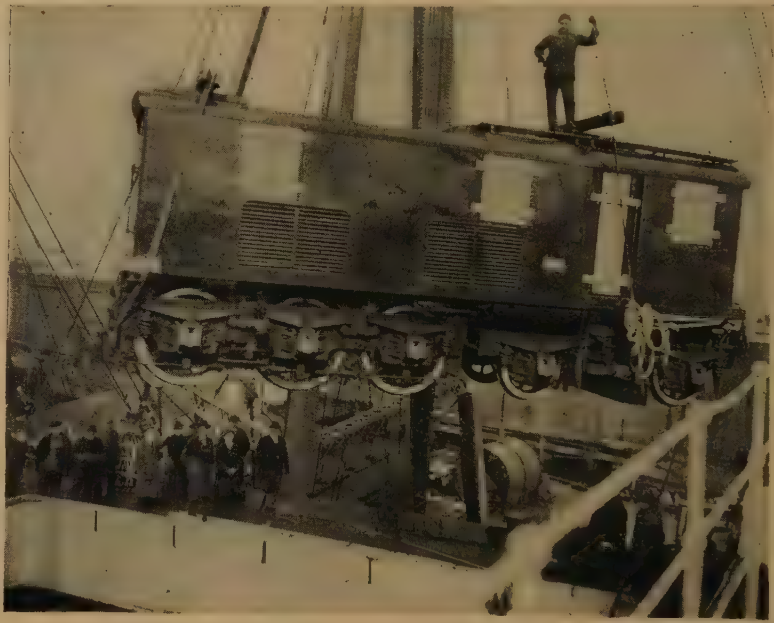


Fig. 2. Loading One of the Half Units of the Paris-Orleans Locomotive on the S. S. *Ontario* for Shipment to France

The remainder of the cab is used to house the various pieces of apparatus, including resistors, contactors, reversers, series-parallel switch, field tappers, high speed circuit breaker and other high voltage equipment, all of which is installed in a protecting structure arranged to prevent accidental contact, but to permit easy access for inspection and maintenance. The compressors, blower sets and storage battery are located so as to give easy access and to permit passage through the compartment.

Electrical Equipment

The driving motors are of the bipolar gearless type designated GE-101-A and built for operation at 750 volts per commutator with two motors in series. The field poles, field coils and brush-holders are mounted on the truck transoms, and the truck platform and cab structures form a part of the magnetic path. The nominal one hour rating of this motor based on temperature rise by thermometer of 75 deg. C. after a one hour run with all covers off and operated on tapped field (75 per cent) is as follows:

At 675 volts...... 395 French horse power
At 750 volts...... 408 French horse power

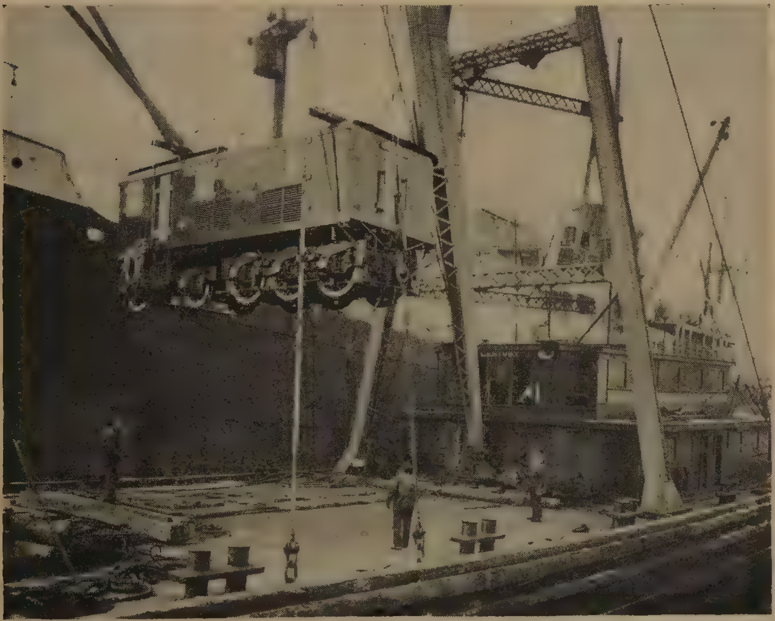


Fig. 3. Loading the Other Half Unit of the Paris-Orleans Locomotive from a Lighter for Shipment to France

The continuous blown rating based on a temperature rise of 120 deg. C. by resistance and operating on either full or tapped field is 355 French horse power at 675 volts. The calculated one hour rating when blown with the same amount of air, and operated at 675 volts is 470 French horse power at 120 deg. C. rise (by resistance). Under emergency conditions, the locomotive can be operated without blowers at reduced rating for a limited time. In order to protect the motor from dust and dirt and to permit the efficient use of forced ventilation, the under sides of the transom are covered with steel plates, and openings are provided for the forced ventilation. While the locomotive is not equipped for regenerative electric braking, space is provided for the installation of equipment for this purpose and the motors will operate successfully during regeneration with trolley voltages as high as 1800 volts.

Control Equipment

The control equipment is electro-pneumatically operated, is non-automatic, single unit and gives steps and groupings of motors as given in Table II.

Upon starting, six motors are connected in series together with an adjustable accelerating resistance. Resistance is gradually short circuited until the motors are connected in series directly across the line. The accelerating handle is then moved to the first series-parallel notch of the controller and a pneumatically operated switch reconnects the motor circuits in series parallel with the accelerating resistance again in series. The full parallel connection of three groups of two motors each in series is obtained in a similar manner.

For speeds above the full field running connections, tapped field positions are provided which disconnect a portion of the motor field winding from the circuit. Two of these steps can be obtained in the series and series-parallel positions and one in the full parallel position. The tapped field connections are

TABLE II

10 resistance steps	all 6 motors in series
1 full field running step	all 6 motors in series
2 tap field running steps	all 6 motors in series
7 resistance steps	3 motors in series in each of 2 groups
1 full field running step	3 motors in series in each of 2 groups
2 tap field running steps	3 motors in series in each of 2 groups
6 resistance steps	2 motors in series in each of 3 groups
1 full field running step	2 motors in series in each of 3 groups
1 tap field running step	2 motors in series in each of 3 groups

obtained by moving a selective handle on the master-controller and are used at the discretion of the operator. Provision is made for disconnecting the motors on either half of the locomotive in emergency, so that the three remaining motors can be operated in series.

A master-controller is located in the left hand side of each operating cab energizing the control circuits by means of a 72-volt supply taken from the storage battery. There are three handles, the main accelerating handle by means of which the accelerating resistance is cut out and the three motor combinations are secured; second, a selective handle for obtaining reduced field connections; third, a reverse handle for controlling the direction of movement of the locomotive. Suitable protective interlocks are provided to insure proper operation of these control handles.

The contactors are air-operated switches which are closed by the pressure of the air applied against a piston. The contactors are opened by a heavy spring acting against the piston.

Overload and short circuit protection is secured by a high speed circuit breaker which trips and inserts resistance in the circuit. After the resistance is inserted, a pair of line contactors then opens the circuit. The high speed of operation greatly reduces the damage that can be done, and in addition, protects the substation apparatus by quickly eliminating excessive power demands. The series-parallel switch and field tappers are pneumatically operated through cam shafts.

Auxiliary Equipment

The auxiliary equipment includes air compressors, blowers and heaters which are operated through a separate circuit taking power from the 1500-volt trolley. The apparatus in the operating cab includes two air gauges, an ammeter and switches for controlling the lights and pantograph collectors. Each cab is heated by six series connected heaters supplied from the 1500-volt trolley.

Forced ventilation for the traction motors is obtained by a multivane type blower, one of which is located directly above each motor. The three blowers on each driving truck are direct connected to an enclosed series wound 1500-volt motor, and arrangements are made to connect the two motors in series to reduce power consumption.

Air Brake Equipment

The air brake equipment is of the French Westinghouse type for double end operation and for control of both locomotive and train. A total of six air brake cylinders are provided, supplied from the main reservoir, having a total capacity of 1500 liters (53 cu. ft.).

Compressed air is furnished by two 1500-volt compressors having a total piston displacement (at the low pressure piston) of about 3600 liters (127 cu. ft.) per minute when delivering air at a pressure of 10 kg. per square centimeter (142 lb. per sq. in.). The compressor is of a two-stage type with horizontal cylinders fitted with single acting pistons. The gear is located centrally between the crank pins in accordance with standard G-E compressor design, which effectively reduces noise, vibration and wear of the bearings.

The locomotive was manufactured jointly by the General Electric Company and the American Locomotive Company. It was ordered by the Paris-Orleans Railway from the Compagnie Francaise Thomson-Houston, the International General Electric Company's associated manufacturing company in France. The Compagnie Francaise Thomson-Houston has received orders for more than $15,000,000 worth of equipment for the Paris-Orleans electrification and orders aggregating $2,500,000 have been placed through the International General Electric Company with the General Electric Company in the United States.

Radio Broadcasting Station KGO

GENERAL ELECTRIC COMPANY, OAKLAND, CALIFORNIA

By Adam Stein, Jr.

Managing Engineer, Radio Department, General Electric Company

How many individuals can accurately describe the face of their watches from memory? Very few.

Ask a number of your acquaintances to tell you what character of numerals appear on the watch face, the shape of the hands, and whether the figure six is like the other figures. The large majority will fail on this simple test despite the fact that they look at the face of their watches many times a day.

Few people can answer these questions correctly; fewer still can tell what is behind the face of the watch.

How many people of the millions who "listen in" know what is behind the broadcast radio program?

Mr. Stein's article is written with the hope that something of interest will be found in it, both by the engineer and by many of that vast army of radio "fans" whose time has been principally devoted to the romantic aspects of radio, to the exclusion of its "works."

It is difficult, if not impossible, to prepare an article of this kind which will convey more than a general idea of the engineering talent and manufacturing skill employed in a highly developed broadcasting service.

Many parts of the modern broadcasting system are as delicate as the parts of a watch, and the equipment taken as a whole is much more intricate.

In order to get KGO "on the air," for instance, 40 drawing lists and 500 drawings, including circuit diagrams, were required before manufacture could begin. The complete circuit diagram for KGO is 18 ft. 6 in. long by 24 in. wide. The switchboards, motor-generator sets, transformers, rectifiers, and other paraphernalia constitute a power plant of considerable magnitude.

The station proper, consisting of the "pick-up" devices, control apparatus, and other equipment employed in the studio and in the power house, together with the mobile equipment used in the field, must all be co-ordinated to the highest degree in order to reproduce faithfully the vibrations of every known type of musical instrument, combinations of these instruments and the widely varying characteristics of the human voice.

KGO was officially placed in operation January 8, 1924. From the reports so far received on the reception of its programs, this Pacific Coast station should establish as enviable a reputation as has its sister station WGY, located near the Atlantic Coast.—E. P. Edwards, Manager, Radio Dept., G. E. Co.

Fig. 1. Studio Building of KGO

The second General Electric broadcasting station, KGO, is located at Oakland, California. While it is designed along the same general lines as WGY, it differs very materially in both electrical refinements and constructional details. The fundamental requirements of broadcasting stations and their operational features have been explained in earlier issues of this magazine.* It is planned, therefore, to tell the story of KGO pictorially, believing that in this way some idea of the magnitude of the engineering and manufacturing problems will be more evident.

In describing the station it is convenient to divide the equipment into four general groups, practically all of which are supplied in duplicate even to the elevated portion of the antenna:

(1) Antenna System
(2) Power Station
(3) Control Room
(4) Studio.

Antenna System

The antenna is of the multiple tuned type with two tuning points as shown in Fig. 6. The flat top portion consists of three phosphor-bronze wires, No. 14 B. & S., spaced twelve feet apart. These wires are each 120 ft. long and are suspended between two towers 150 ft. high and spaced 260 ft. apart. The towers are of the self-supporting type, 19½ ft. square at the base and 3 ft. square at the top.

The counterpoise is shown in Fig. 8 and consists of a network of No. 14 B.&S. phosphor-bronze wires suspended ten feet above the ground. In addition to the wires, the counterpoise includes suitable equalizer coils shown in Fig. 12 and indicated in Fig. 8

---

*"Radio Broadcasting Station WGY," by W. R. G. Baker, April, 1923, p. 194; "Staging the Unseen," by K. D. Hager, September, 1923, p. 594.

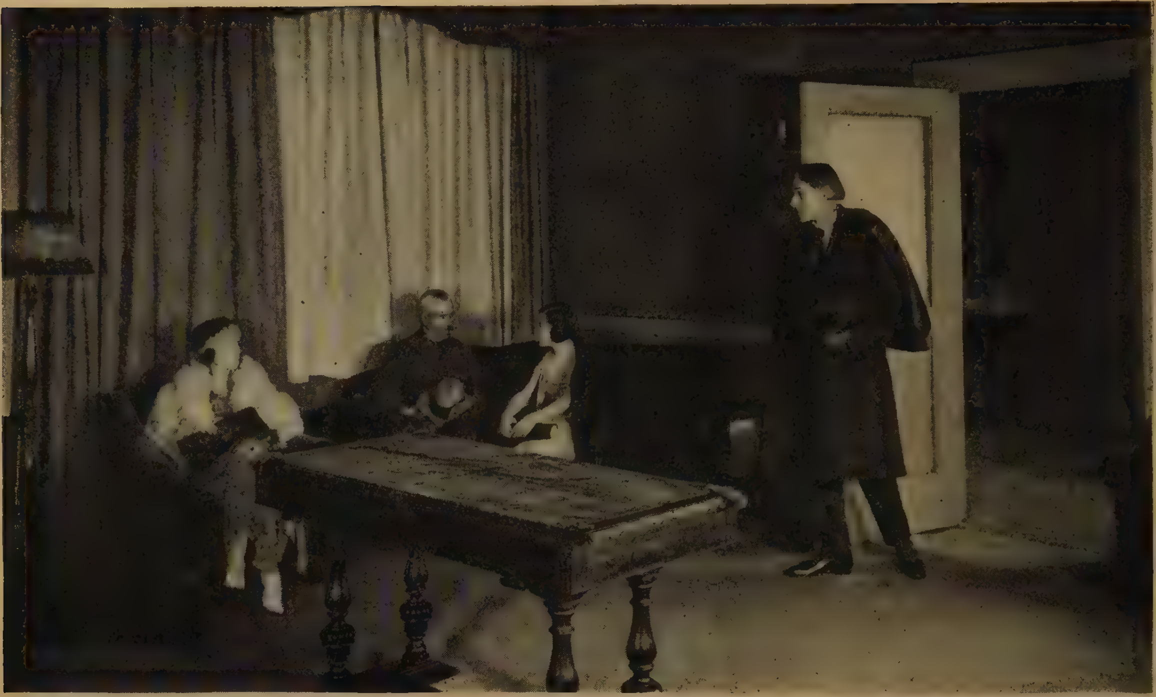


Fig. 2. Reception Room for Artists, Who after Preparing for Their Parts on the Program Await Their Turn in the Silent or Waiting Room Adjacent to the Studio

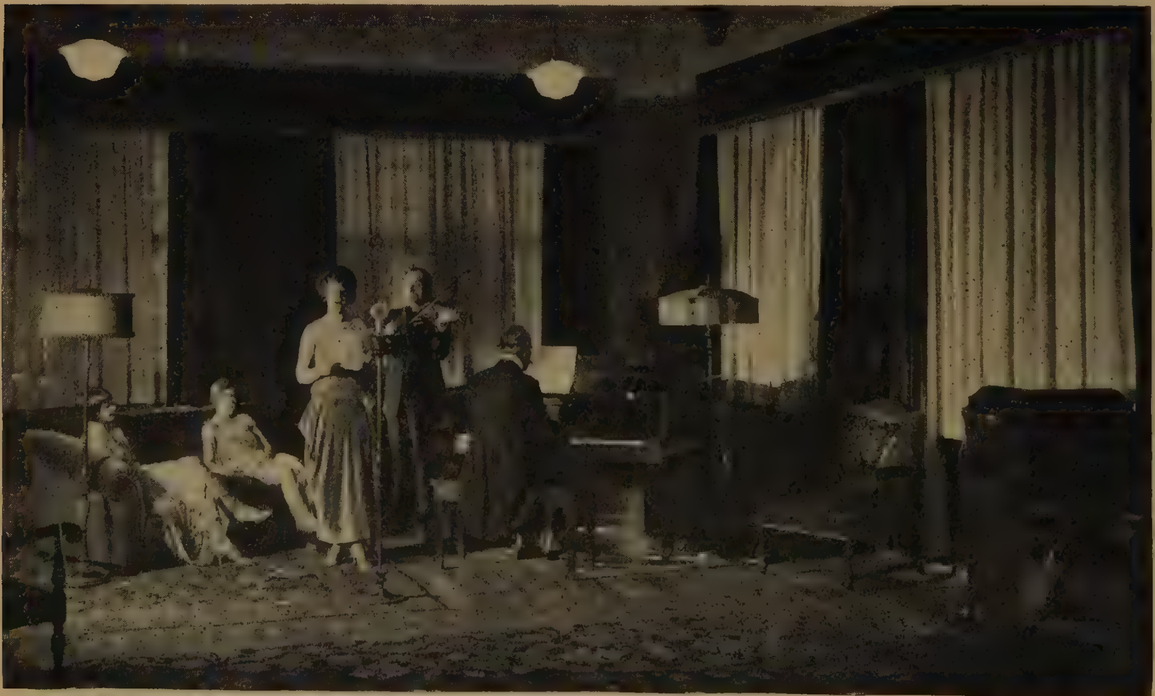


Fig. 3. Main Studio Attractively Furnished, and Equipped with Musical Instruments, Controls, Signal Lights, and the Most Highly Refined Type of Pick-up Devices. A smaller room equipped as an auxiliary studio is located on the same floor

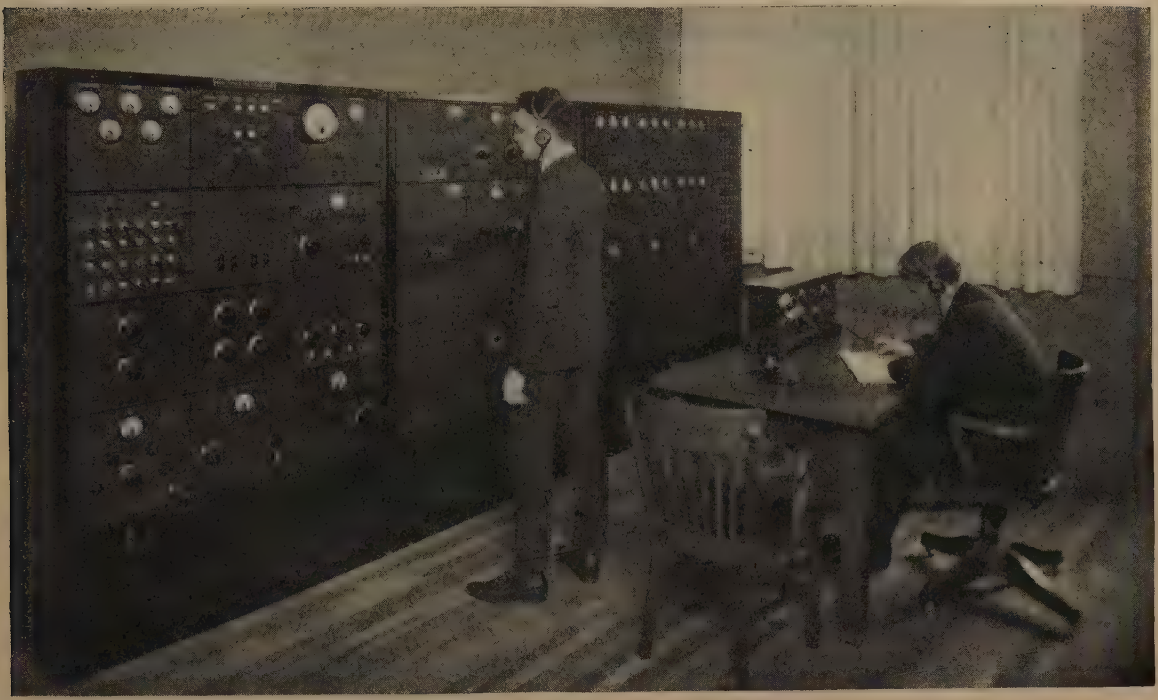


Fig. 4. Control Room, Located Between the Main and Auxiliary Studios. The finished appearance of the equipment is in marked contrast to that of earlier installations which in many cases resembles a laboratory bench

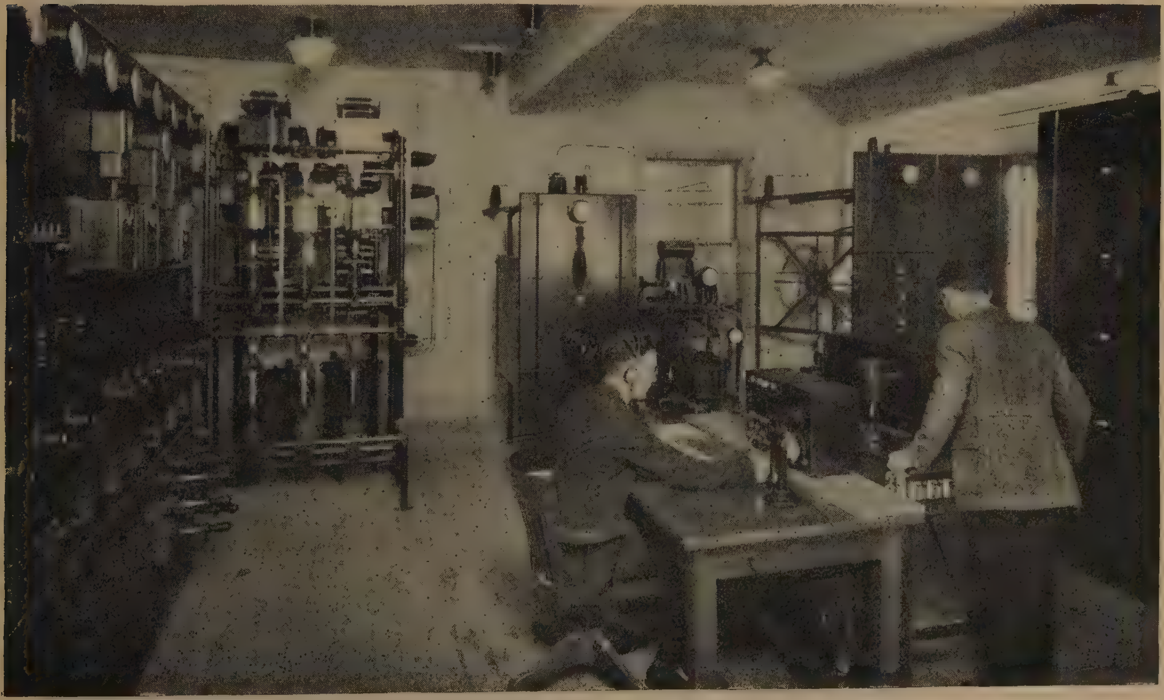


Fig. 5. Power House Room, Located Beneath the Antenna and Counterpoise 1600 ft. Distant from the Studio Building. The substantial calibre of the equipment in this room shows it to be amply entitled to the term "power house apparatus"

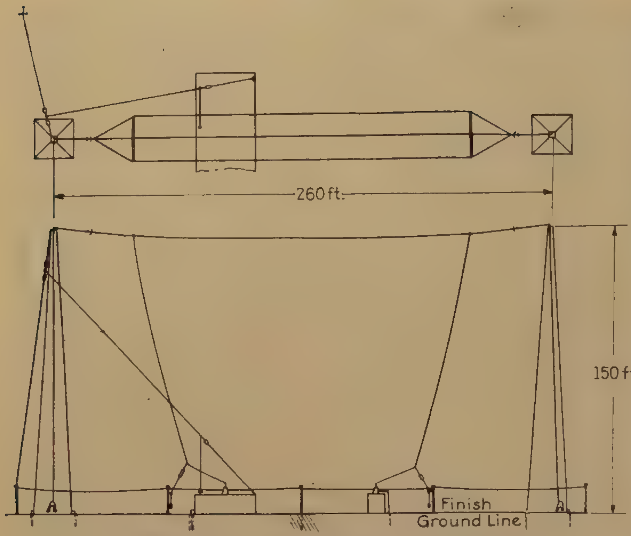


Fig. 6. Side Elevation of the Antenna and Counterpoise Above the Power House. The antenna is of the multiple-tuned type, tuned at two points

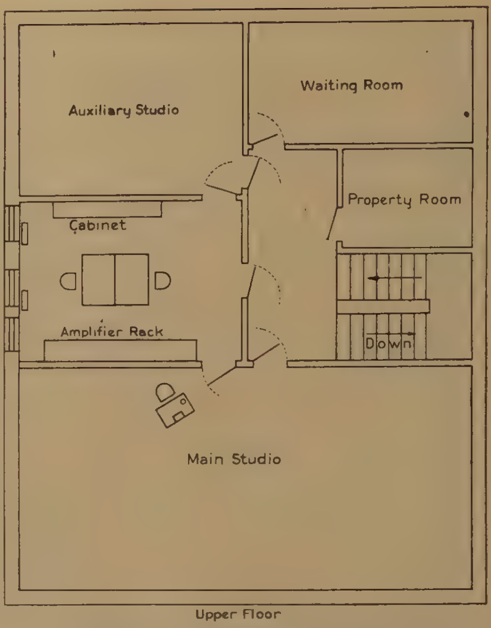


Fig. 7. Plan of the Second Floor of the Studio Building. A photograph of the main studio is shown in Fig. 3, and one of the control room in Fig. 4

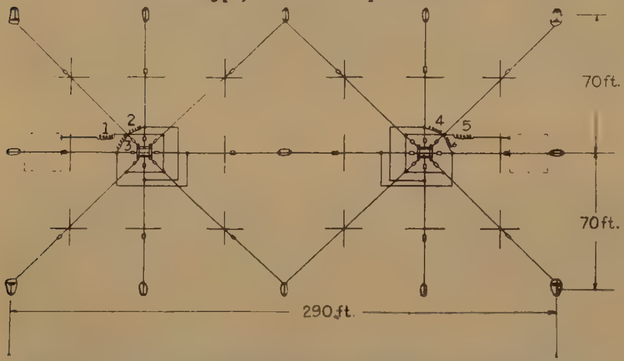


Fig. 8. Plan of the Counterpoise with its Points of Support, Insulators, and Electrical Connections. The numbers *1* to *6* indicate the locations of the equalizer coils, Fig. 12

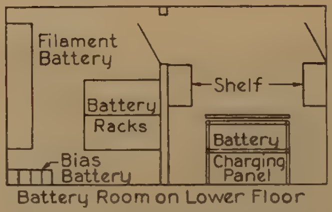


Fig. 9. Plan of the Battery Room on the Ground Floor of the Studio Building

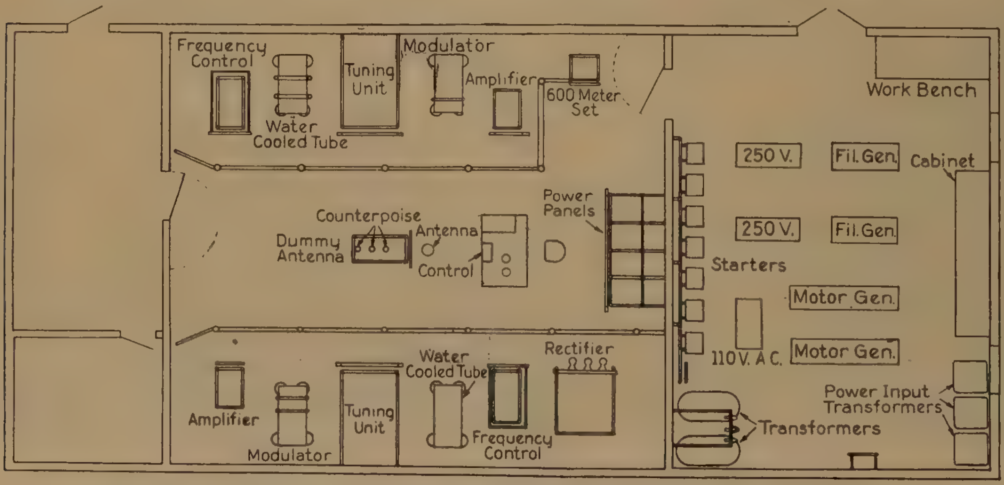


Fig. 10. Plan of the Power House. This is a high-frequency generating station laid out with the same degree of thoughtfulness to detail as is applied in the case of commercial-frequency power stations

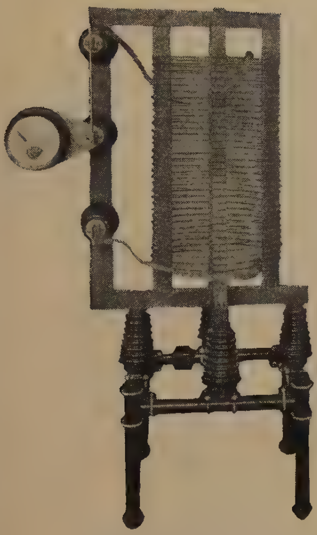


Fig. 11. Antenna Loading Coil used for multiple tuning the antenna. The single-pole double-throw switch at the left permits tuning the antenna quickly to either of two frequencies. The ammeter reads the current in the down lead

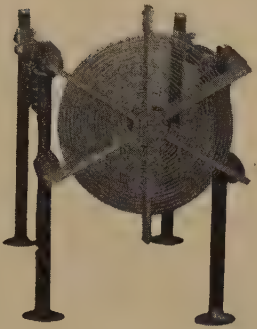


Fig. 12. Counterpoise Equalizing Coil. Six are used, one at each of the numbered locations in Fig. 8

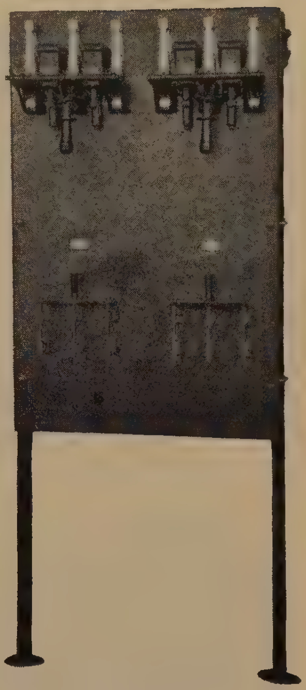


Fig. 13. Line Switch and Circuit Breaker Panel ***(located in power house)***

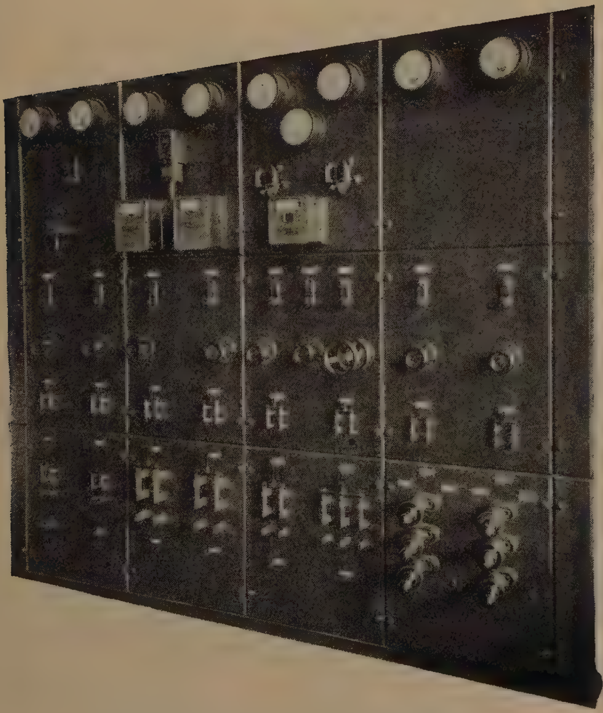


Fig. 14. Panels for Controlling the exciter, a-c. and d-c. motor-generator sets and also for distributing power to amplifiers ***(in power house)***

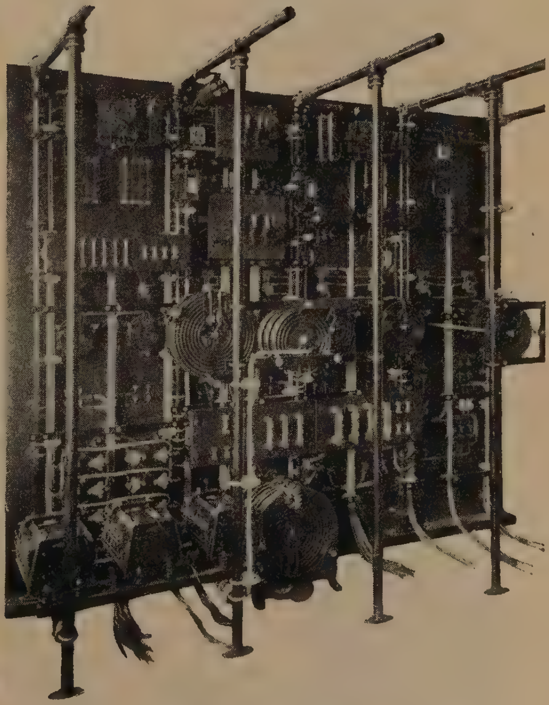


Fig. 15. Rear View of the Power Control Panels Shown in Fig. 14

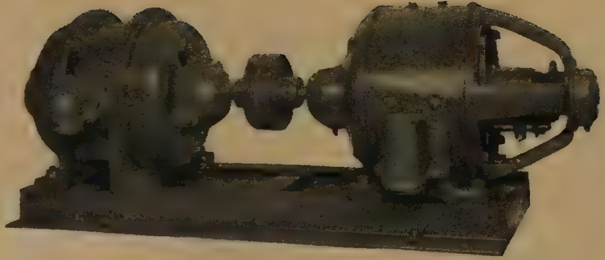


Fig. 16. Exciter Motor-generator Set for Supplying Field Excitation to All the Generators and Power for the Control Circuits (*in power house*)

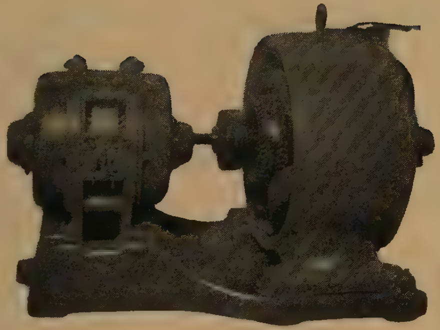


Fig. 17. Kenotron Filament A-c. Motor-generator Set (*in power house*)

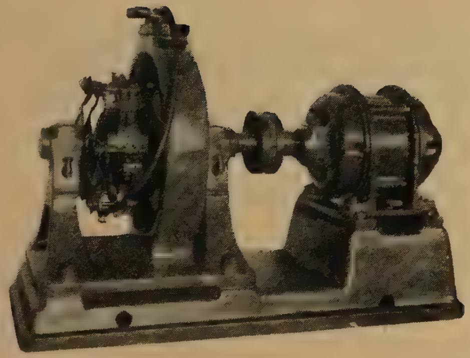


Fig. 18. Pliotron Filament D-c. Motor-generator Set for Supplying the Oscillator, Modulator, and Power Amplifier Units (*in power house*)

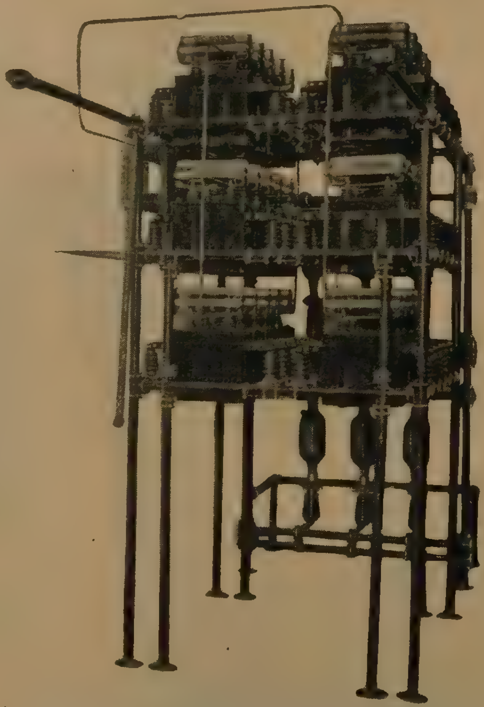


Fig. 19. Kenotron Rectifier Unit for Supplying all High-voltage Direct Current (*in power house*)

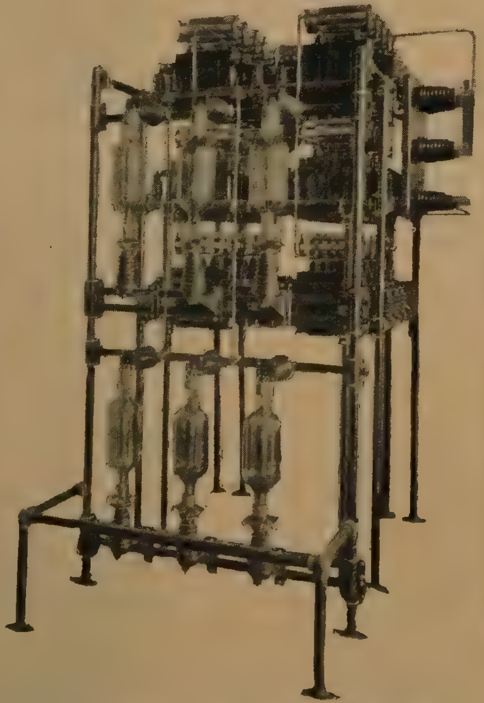


Fig. 20. Another View of the Kenotron Rectifier Unit Shown in Fig. 19

Fig 21. Kenotron Plate Double-Y Transformer (*in power house*)

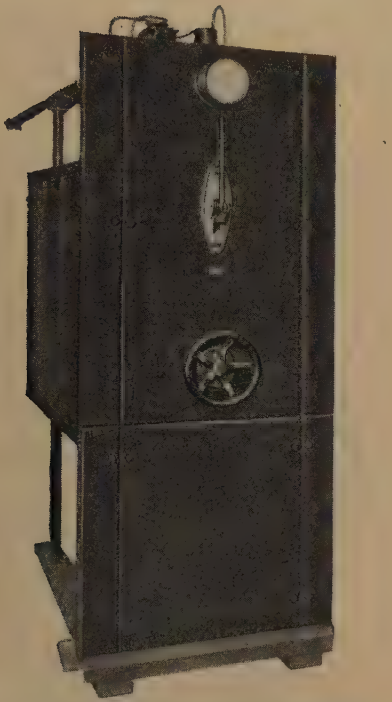


Fig. 22. Frequency-control Unit for Establishing the Frequency of Transmission (*in power house*)

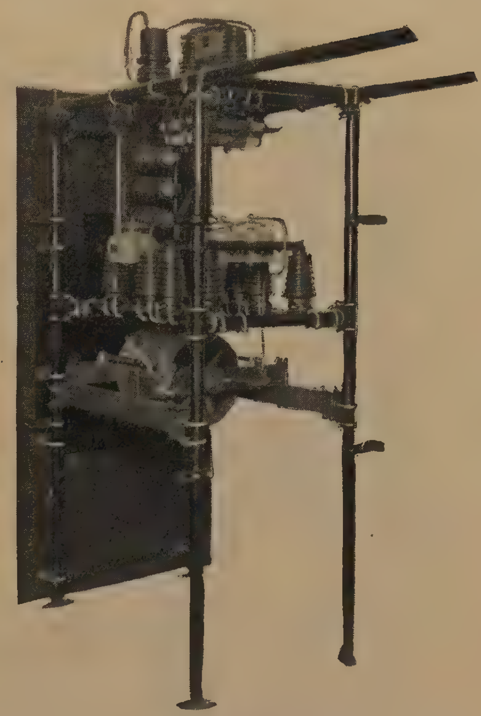


Fig. 23. Rear View of Frequency-control Unit with Shields Removed

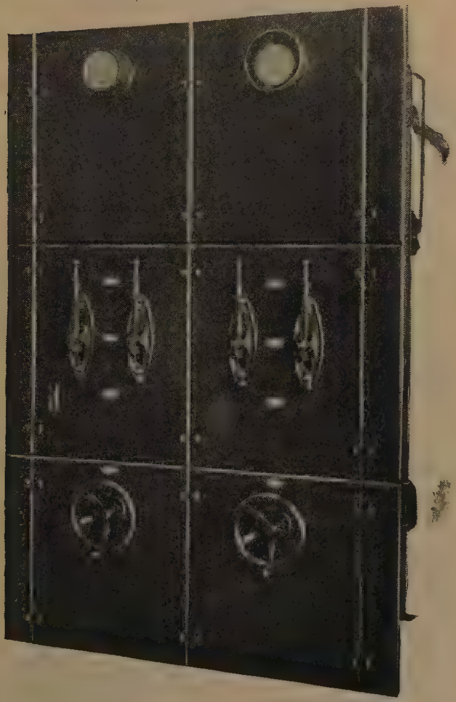


Fig. 24. Tuning and Coupling Unit for Transferring High-frequency Energy to Antenna and also Eliminating Harmonics (*in power house*)

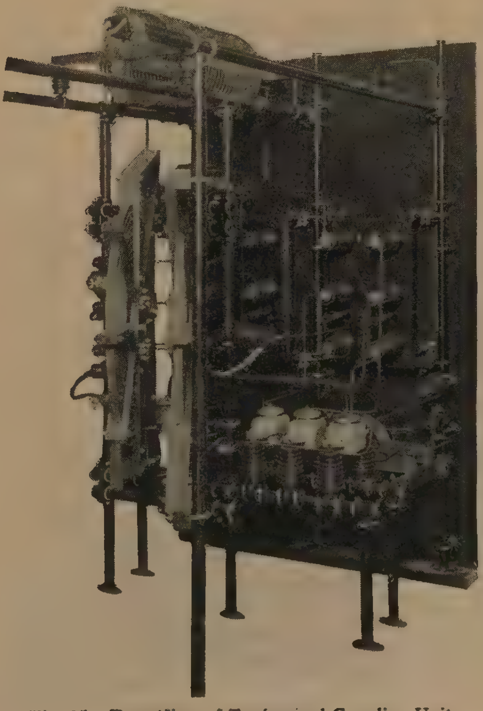


Fig. 25. Rear View of Tuning and Coupling Unit

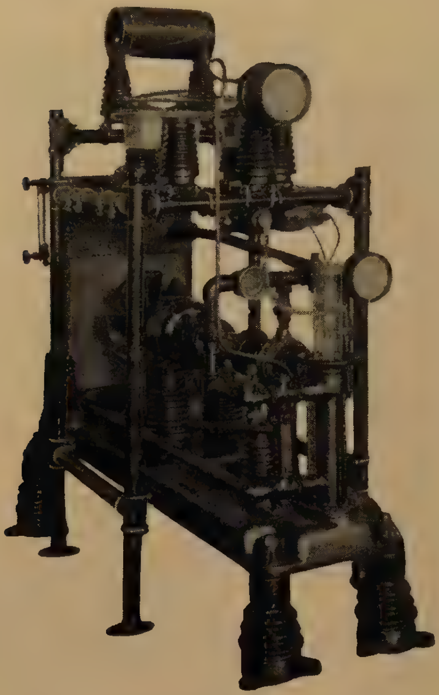


Fig. 26. High-frequency Water-cooled Tube Unit (*in power house*)

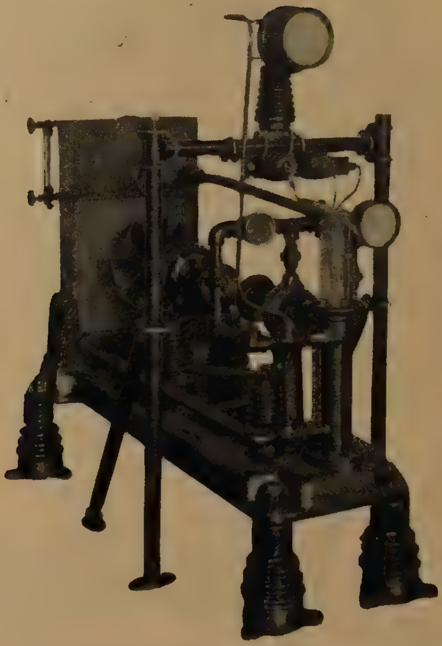


Fig. 27. Modulator Water-cooled Tube Unit (*in power house*)

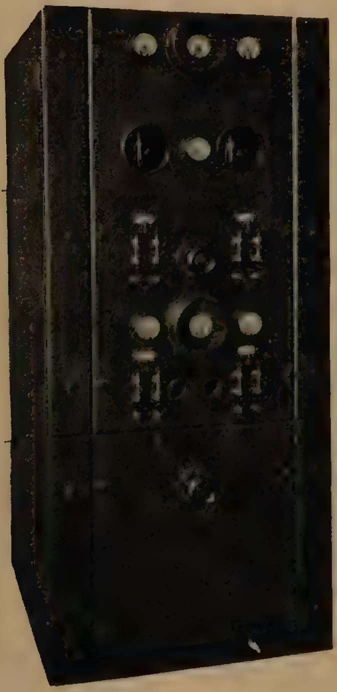


Fig. 28. Power Amplifier Unit (*in power house*)

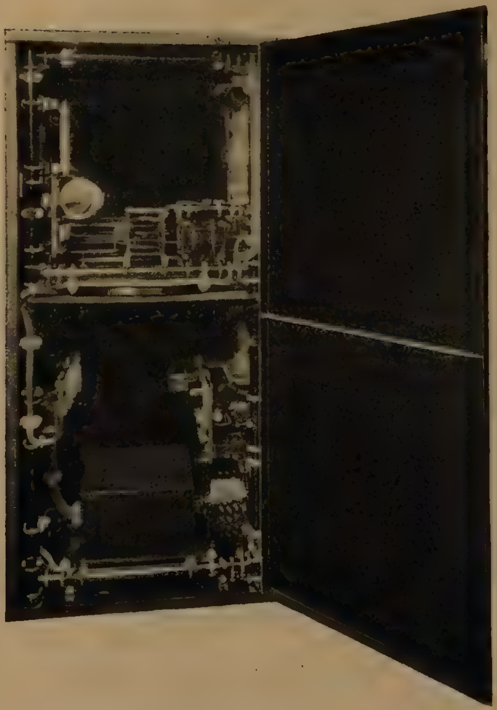


Fig. 29. Side View of Power Amplifier Unit

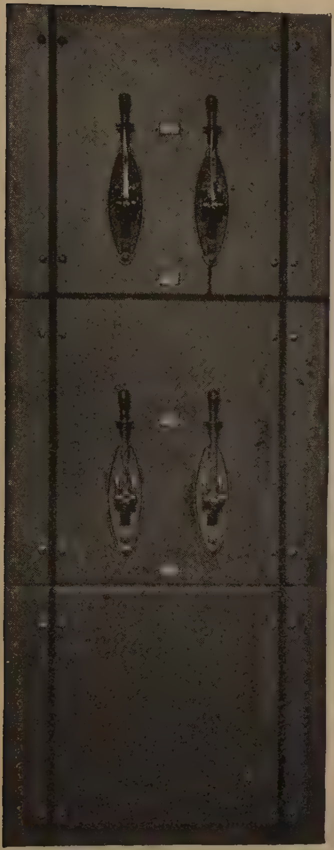


Fig. 30. Artificial Antenna Unit Used when Making Routine Tests or Locating Trouble (*in power house*)

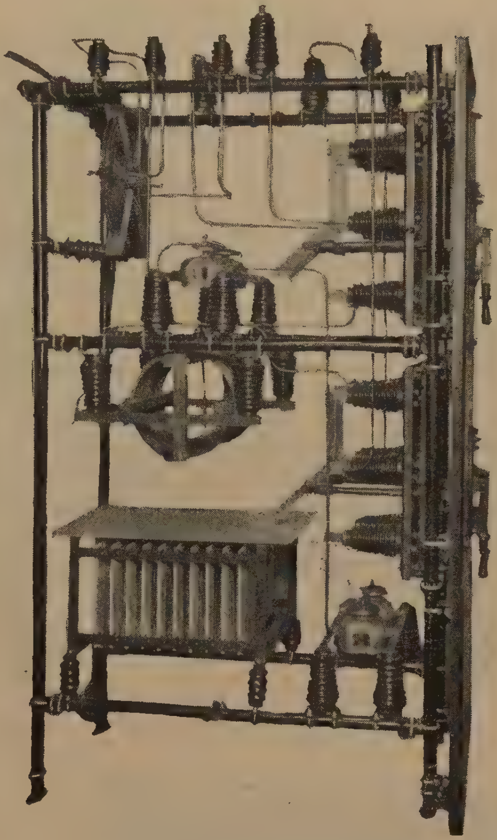


Fig. 31. Side View of Artificial Antenna Unit

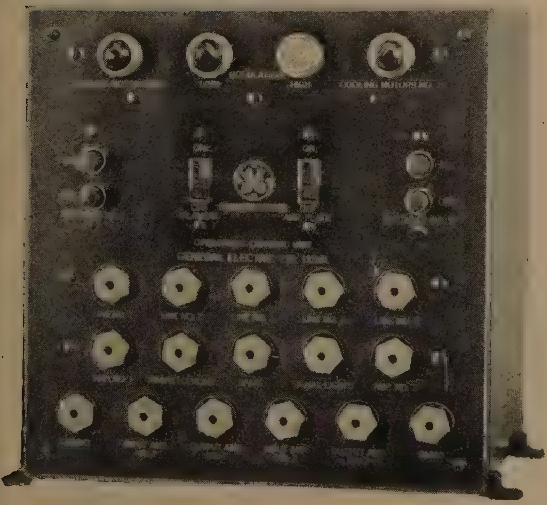


Fig. 32. Operator's Control Unit (*in power house*)

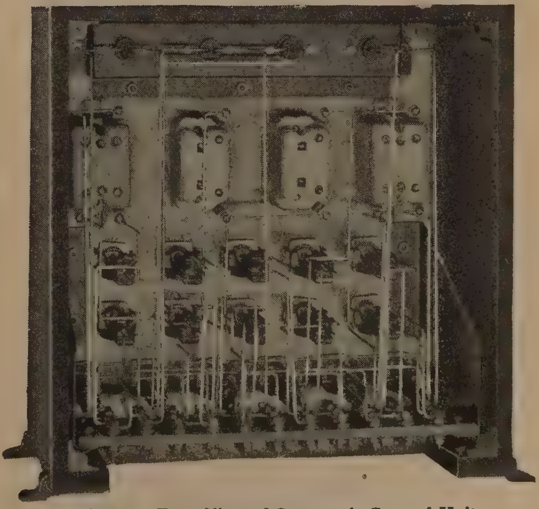


Fig. 33. Rear View of Operator's Control Unit

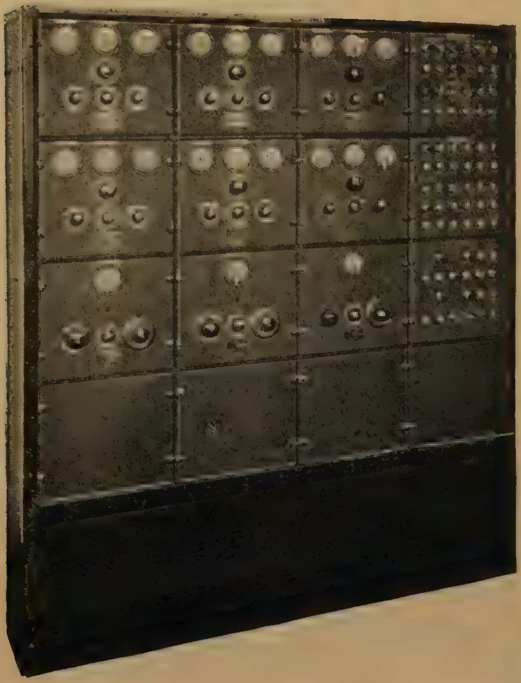


Fig. 34. Microphone Amplifier Bank. Its output is transferred to the unit shown in Fig. 36 (*in studio control room*)

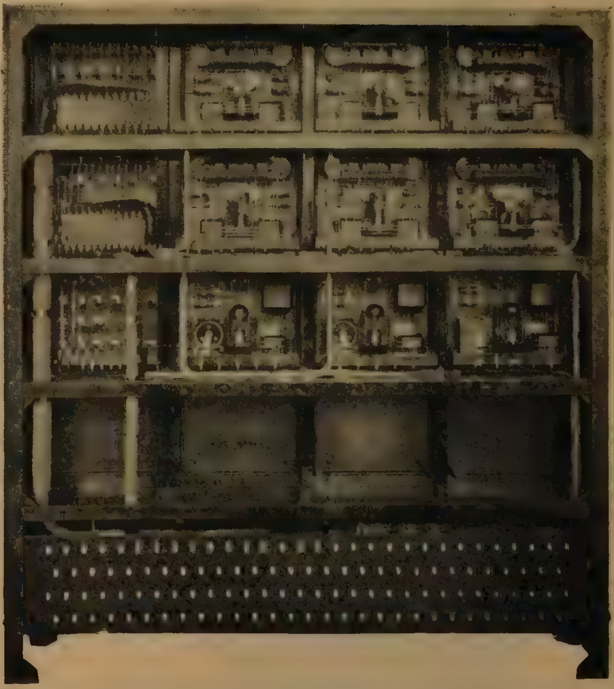


Fig. 35. Rear View of Microphone Amplifier Bank

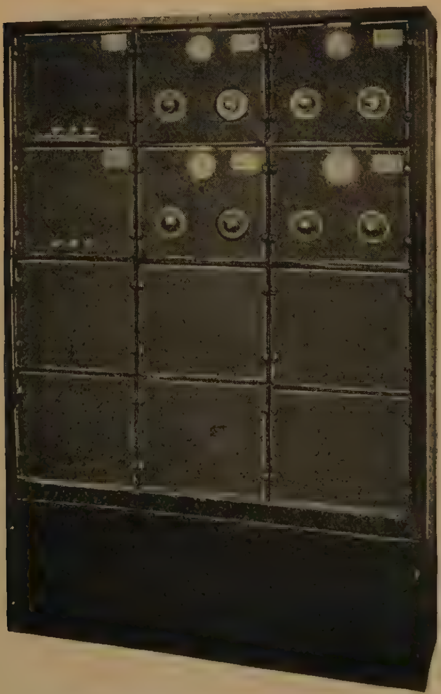


Fig. 36. Intermediate Amplifier Bank. Its output is transferred to the unit shown in Fig. 38 (*in studio control room*)

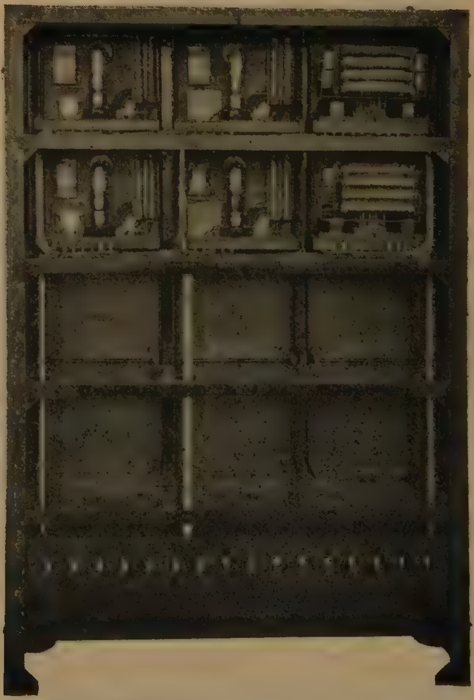


Fig. 37 Rear view of Intermediate Amplifier Bank

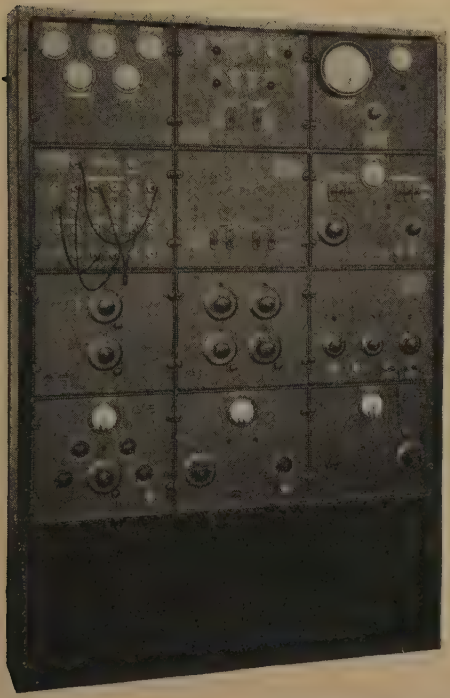


Fig. 38. Monitoring and Time Signal Bank. Its output is transferred underground to the power house (*in studio control room*)

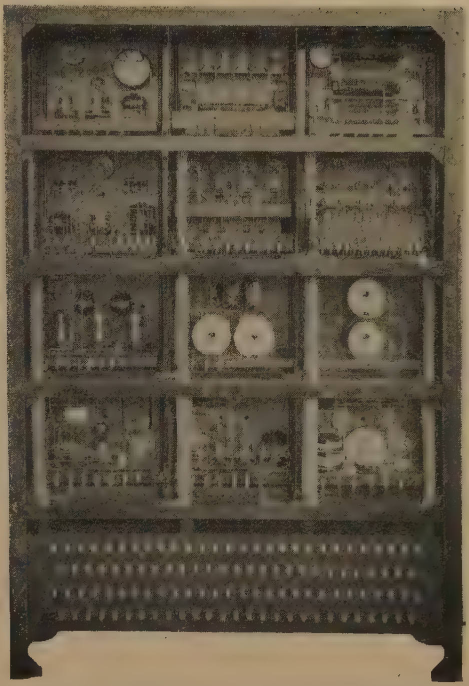


Fig. 39. Rear view of Monitoring and Time Signal Bank

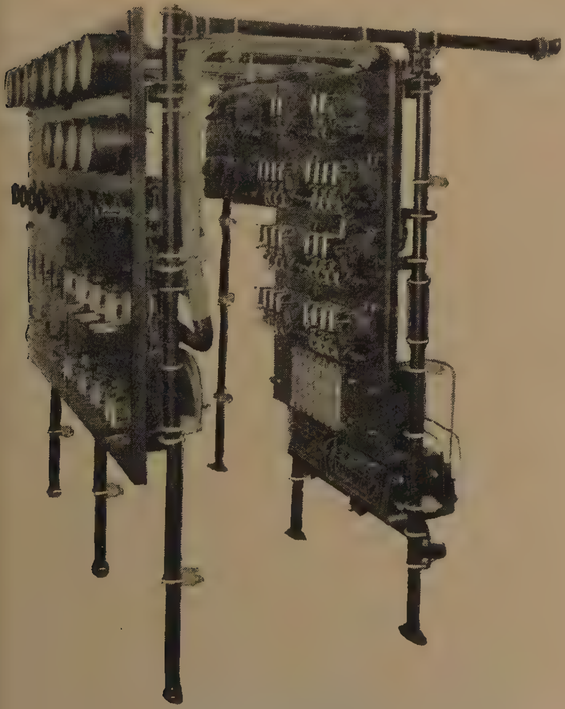


Fig. 40. Battery and Generator Control Panel (*in battery room*)

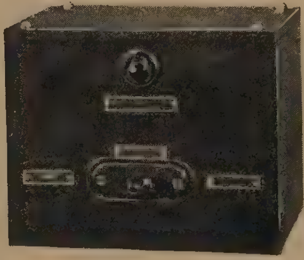


Fig. 41. Director's Control Unit (*in studio room*)

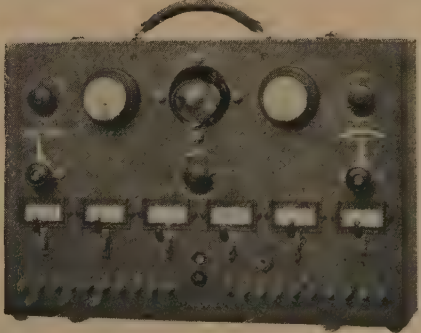


Fig. 42. Portable Control Unit for Broadcasting Church Services, etc.

by the numbers one to six inclusive. Fig. 11 illustrates the construction of the multiple tuning coils. A view of the towers and the elevated portion of the antenna system is shown in the frontispiece of this issue.

Power Station

The power station (Fig. 10) contains all the equipment for the generation, modulation, and control of the high-frequency power.

The main power supply for KGO is obtained from a 220-volt, 60-cycle, 3-phase source, and upon entering the building passes through the line switch and circuit-breaker panel, shown in Fig. 13, to the power-control panel illustrated in Figs. 14 and 15. The power panel contains the equipment necessary for the control and distribution of power to the necessary motors, transformers, and other apparatus. As shown in Fig. 14, the power panel comprises four sections of standard slate switchboard units. The left-hand section provides controls and meters for the 250-volt exciter (Fig. 16) which supplies field excitation for all the generators and power for the operation of the various control circuits. The next section controls the alternating-current motor-generator set (Fig. 17) for kenotron filament supply. The third panel controls the direct-current filament motor-generator set (Fig. 18) for the oscillator, modulator, and power amplifier units. The fourth panel furnishes means for distributing the power supply to the various amplifiers.

All high-voltage direct current is supplied by the kenotron rectifier equipment shown in Figs. 19 and 20. This equipment with its filter provides a 15,000-volt direct-current supply having a ripple of less than 0.1 of one per cent. Associated with the rectifier is an auto-transformer which permits a variation in output voltage from 4000 to 15,000 volts direct current. The double-Y transformer shown in Fig. 21 furnishes energy to the kenotron plate circuits.

The main generation units are shown in Figs. 22 to 26 inclusive. Figs. 22 and 23 illustrate the equipment necessary for establishing the frequency of transmission and is designed to permit extremely close adjustment. The tuning and coupling unit is shown in Figs. 24 and 25. This apparatus in addition to providing a means of transferring the high-frequency energy to the antenna system also eliminates any harmonics that may have been generated and amplified in the associated units.

One of the most interesting pieces of equipment is the complete water-cooled tube unit shown in Fig. 26. The combination of a radiator, fan, and pump provides a sufficient circulation of cooling water to prevent the anode of the tube from overheating. A dial thermometer is shown on the right-hand side of the tube and a water-flow indicator on the left. The superstructure permits mounting the necessary equipment in close proximity to the tube.

For the modulation of the high-frequency current two additional units are required. They are shown in Figs. 27, 28 and 29. The water-cooled tube equipment (Fig. 27) is used as a modulator tube and is preceded in the circuit by the power amplifiers (Figs. 28 and 29).

In order to make routine tests and locate any trouble that might occur, the regular antenna may be replaced by the artificial antenna shown in Figs. 30 and 31. This eliminates any interference that might occur due to operating the station at times when a program was not scheduled. A very important part of the power station equipment is the control unit shown in Figs. 32 and 33. Circuits between the control room, which is located 1600 ft. from the power station, are terminated at the jacks designated by Line No. 1, etc. During a program one line is plugged through to the jack marked Amp. No. 1 or Amp. No. 2. This particular circuit then acts as the connecting link between the control room and the power station. Two other circuits are also in use during a program, one of which is used for signalling purposes, the other for communication between the control and power operators. Jacks are also provided so that the operator may check the functioning of the power amplifiers. The switches provide means for starting, stopping, or transferring various units of the power equipment. Signal lights located at the top of the panel indicate the two extremes of modulation and check the operation of the water-cooled tube units.

In addition to the control unit the station operator is able to observe the modulation by means of an oscillograph so that during a program the condition of the entire power station may be readily checked and maintained in proper operation.

Control Room and Studios

The two studios and control room are located in the building shown in Fig. 1 which is 1600 ft. from the power station. The control room is between the studios and is so arranged that both studios are under the direct observation of the control operator.

The general arrangement of the studio building is shown in Figs. 7 and 9.

The control room equipment consists chiefly of the three amplifier and control banks shown in Figs. 34 to 39 inclusive. The microphone amplifier bank, Figs. 34 and 35, contains the various low-powered amplifiers for the pick-up devices used in the studios. Means are employed whereby any pick-up device can be switched to the desired group of amplifiers, since certain pick-up devices require different amplifiers than others. This also permits switching amplifier units in case of trouble. The output of the microphone amplifier bank is transferred to the intermediate amplifier bank shown in Figs. 36 and 37. The amplifiers in the intermediate amplifier bank are arranged so that they may also be switched very rapidly, in order to prevent any interruption in the program. Figs. 38 and 39 show the monitoring and control bank. Among other things this bank contains the time signal receiver, radio receivers for checking the quality, the antenna power indicator, and the various selector relays. From this bank the circuit passes underground to the power station.

The complete power equipment consisting of batteries, generators, and power control apparatus is located in a separate room. Fig. 40 illustrates the battery and generator control panel.

The equipment for the studio consists of the usual musical instruments, signal lights, pick-up devices, and controls. The director's control unit is shown in Fig. 41. The pick-up devices while essentially those used at WGY have been greatly refined with a corresponding increase in the accuracy of reproduction.

The Belt Driven Edison Bipolar Dynamos

By W. S. Andrews

General Engineering Laboratory, Schenectady, N. Y.

The author writes an interesting sketch of some of Edison's historic dynamos. The data given in tabular form show the details of design. In this connection it is interesting to recall how Edison refused to bow to the scientific belief of the day that the internal resistance of a dynamo should equal the external resistance. Edison, not wishing to lose half of the energy generated in the machine itself, made his armatures with a low resistance and thus increased the efficiency of the machine enormously. This was characteristic of the man who always tried things for himself rather than be bound by ready-made theories.—Editor.

The first commercial type of Edison's dynamo was built at Menlo Park, N. J., in 1880, and a few of these machines were installed during that year. When the Edison Electric Light Company seriously began to undertake commercial operation in 1881, this machine was redesigned and the new machine was termed the "Z" dynamo. The field magnets were very long and the general appearance severely simple. It was constructed primarily for good service rather than for fine appearance. These machines were capable of running sixty 110-volt 16-c-p. lamps without overheating, and as lamps in those days consumed about five watts per candle, they might be rated as about 5 kw. machines. The public demand for them soon exceeded the production facilities at the Menlo Park Works, so Mr. Edison leased the Aetna Iron Works in Goerck Street, New York City, which was then named the "Edison Machine Works." Hundreds of "Z" dynamos were built there during the early eighties and were shipped not only to all parts of the United States, but also to England and the continent of Europe. A dozen of them were installed in the Crystal Palace Electrical Exposition at Sydenham, England, which was the largest isolated plant thus far attempted; it was started January 14, 1882. It soon became necessary to make larger generators, and this was accomplished by adding an extra field magnet to the "Z" machine and lengthening its armature and base to suit. This enlarged machine was named the "L" Dynamo. A still larger size was afterwards built with three field magnets, all of the same size as those of the original "Z" machine, and again extending the length of armature and base. This third machine was styled the "K" Dynamo.

The "Z," "L" and "K" machines were capable of running respectively 60-150-250 lamps, and were the three original sizes of the old type Edison Bipolar Dynamos. A tabulation of the mechanical and electrical features of these three dynamos is given in this article.

Later on, all these machines were remodelled; the field magnets were made considerably shorter, thereby reducing the reluctance of the magnetic circuits, and increasing their efficiency, also other changes in design of a minor character were made which materially improved their general appearance. The first of these remodelled machines was called the "H" which was followed by five smaller machines termed respectively Y, S, T, R and G.

A further improvement was subsequently made by replacing the multiple field magnets with a single magnet of enlarged proportions, and a line of thirteen standard bipolar dynamos were designed and built on these lines, ranging in capacity from 250 watts to 150 kw. These machines were extensively

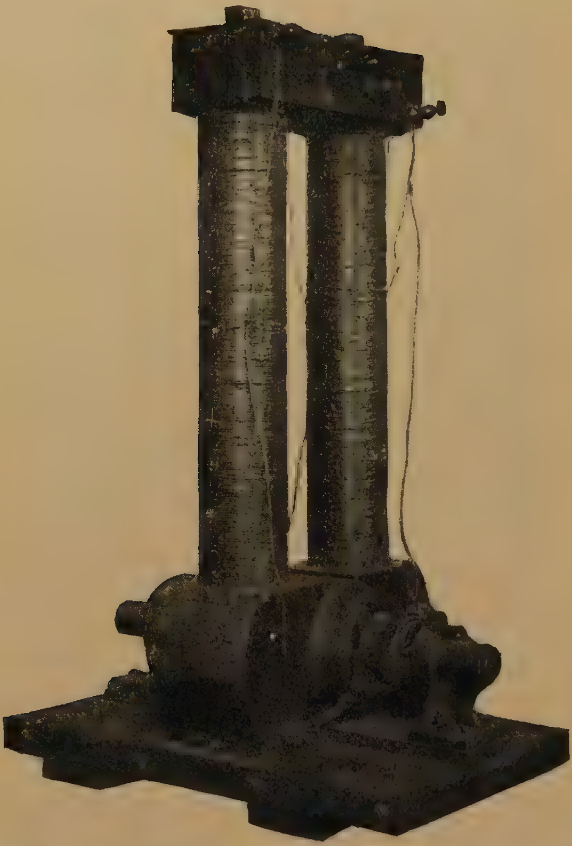


Fig. 1. "Z" Dynamo. The first type of commercial Edison Bipolar Generator; capacity about 5 kw.

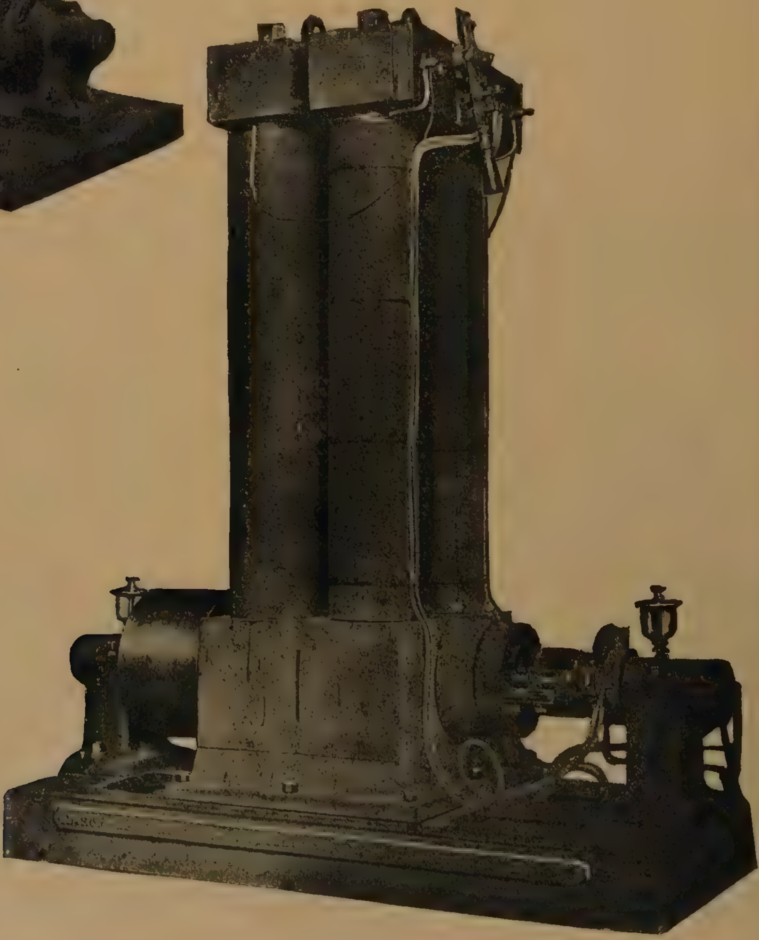


Fig. 2. "L" Dynamo. Enlargement of "Z" Dynamo to meet increased commercial requirements: capacity about 12 kw.

employed in central station and isolated plants until they were finally displaced by the various types of multipolar machines.

It is a fact well worthy of notice that Edison's original conception of a dynamo with an armature of very low resistance, as compared with the total resistance of the electrical circuit, *was embodied in his first model of a bipolar machine.*

The universal practice at that time was to divide up the total resistance of a circuit about evenly between the armature and the outside line, and the idea of making the armature resistance only a small fraction of the outside resistance was ridiculed in scientific circles of that period. Subsequent developments demonstrated Mr. Edison's clear perception of what was then an obscure electrical requirement.

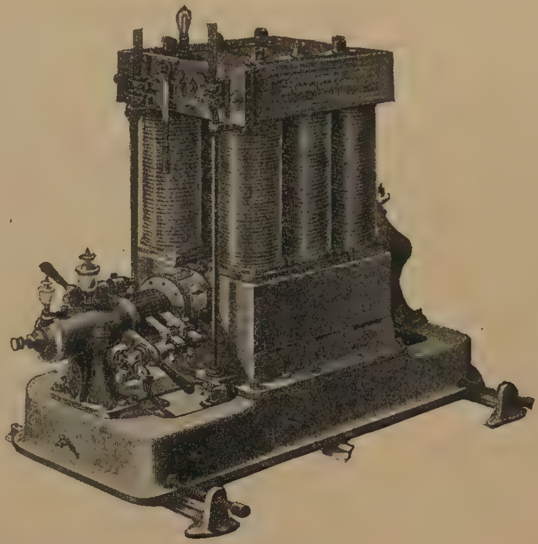


Fig. 4. "H" Dynamo. A later type of Edison Bipolar Generator with shorter field magnets; capacity about 45 kw.

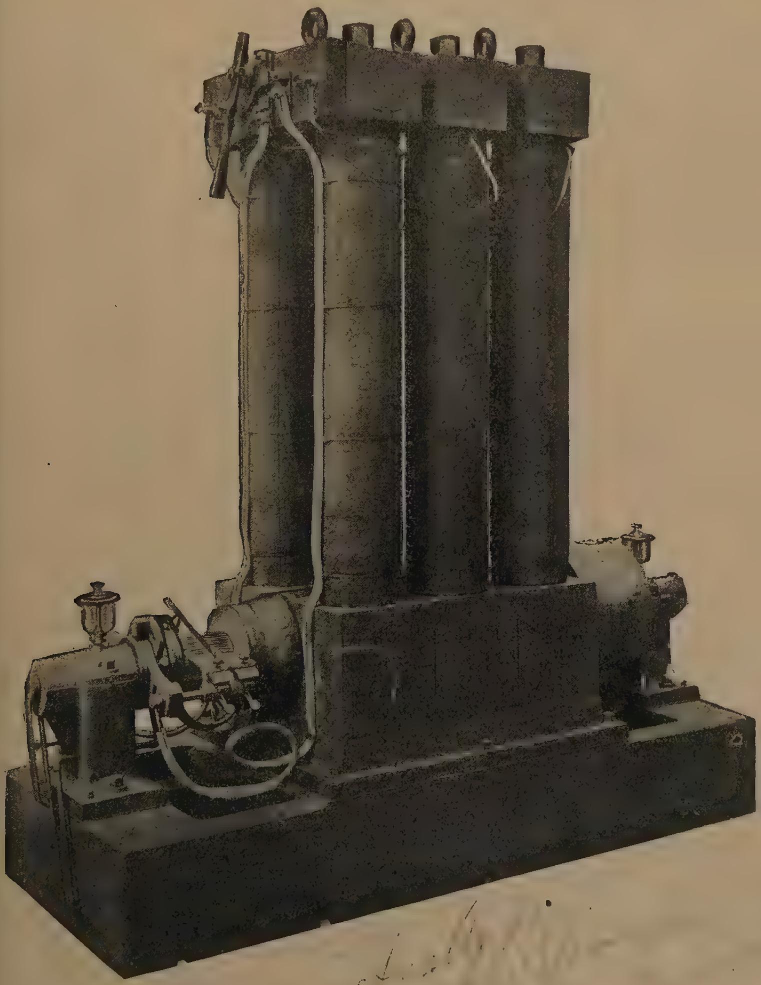


Fig. 3. "K" Dynamo. A further enlargement of the original "Z" Dynamo; capacity about 21 kw.

TABLE OF MAGNET CONSTANTS

Dynamo Symbols	Z	L	K
Number of cores	2	4	6
Length of iron core	42¼ in.	42$\frac{13}{16}$ in.	42$\frac{13}{16}$ in.
Diameter of iron core	6½ in.	6½ in.	6½ in.
Weight of wire on each core	65 lb.	65 lb.	65 lb.
Layers of wire on each core	6½	6½	6½
Convolutions per layer	550	550	550
Size of wire—covered	0.078 in.	0.078 in.	0.078 in.
Size of wire—bare	0.058 in.	0.058 in.	0.058 in.
Resistance of each core	20	20	20
Total magnetic resistance	40	20	13⅓
Distance from center to center	15 in.	15 in.	15 in.
Size of top piece	6 in. × 8 in. × 24 in.	6 in. × 8 in. × 24 in.	6 in. × 8 in. × 24 in.

TABLE OF ARMATURE CONSTANTS

"A" Lamps, 103 Ohms (Hot), 95 Volts

Dynamo Symbols	Z	L	K
Outside diameter of armature finished	10 in.	10.5 in.	10.5 in.
Diameter of iron core of armature	9$\frac{11}{16}$ in.	9$\frac{11}{16}$ in.	9$\frac{11}{16}$ in.
Effective length of armature	11 in.	22 in.	30
Length of iron core of armature	9½ in.	19$\frac{11}{16}$ in.	29⅝ in.
No. of divisions in armature	74	54	64
No. of loops per division	2	2	1
No. of wires per loop	6	6	10
Diameter of wire—covered	0.057 in.	0.085 in.	0.085 in.
Diameter of wire—bare	0.042 in.	0.065 in.	0.065 in.
No. of circular mils in each loop	10584	25350	42250
Total length of wire around armature per division	93 in.	150 in.	90 in.
Effective length of wire on armature per division	44 in.	88 in.	60 in.
Length of end, or dead wire	49 in.	62 in.	30 in.
Average resistance of armature at 60° F.	0.14	0.068	0.03
Resistance of active wire of armature at 60° F.	0.0662	0.03989	0.02
Resistance of end wire of armature at 60° F.	0.0738	0.02811	0.01
Resistance of armature at normal running temp. 160° F.	0.17	0.082	0.0364
Resistance of active wire of armature at 160° F.	0.08037	0.04842	0.02428
Resistance of end wire of armature at 160° F.	0.08963	0.03358	0.01212
Percentage of active wire in armature	47.3 per cent	52 per cent	66.6 per cent
Average field resistance of magnet	40	20	13.33
No. of lamps	60	150	250
Resistance of lamps (hot)	1.717	0.687	0.412
Resistance of lamps and field in multiple arc	1.6463	0.6641	0.4
Total resistance of circuit, lamps in multiple arc, with field and armature at 160° F. in series	1.8163	0.7461	0.4364
Absolute e.m.f. of entire circuit	104.7	106.7	103.6
Percentage of loss of e.m.f. in armature	9¼ per cent	11 per cent	8.3 per cent
Amperes of total circuit	56.9	143	237.5
Total foot-pounds absorbed in armature	24382	74282	90956
Foot-pounds absorbed in effective surface of armature	11527	43862	60670
Foot-pounds absorbed in armature end	12755	30420	30285
Square inch of effective armature surface	345	726	990
Foot-pounds per square inch of effective armature surface	33.4	60.4	61.4
Average revolutions per minute	1200	850	900
Feet speed per minute of armature face	3140	2340	2560

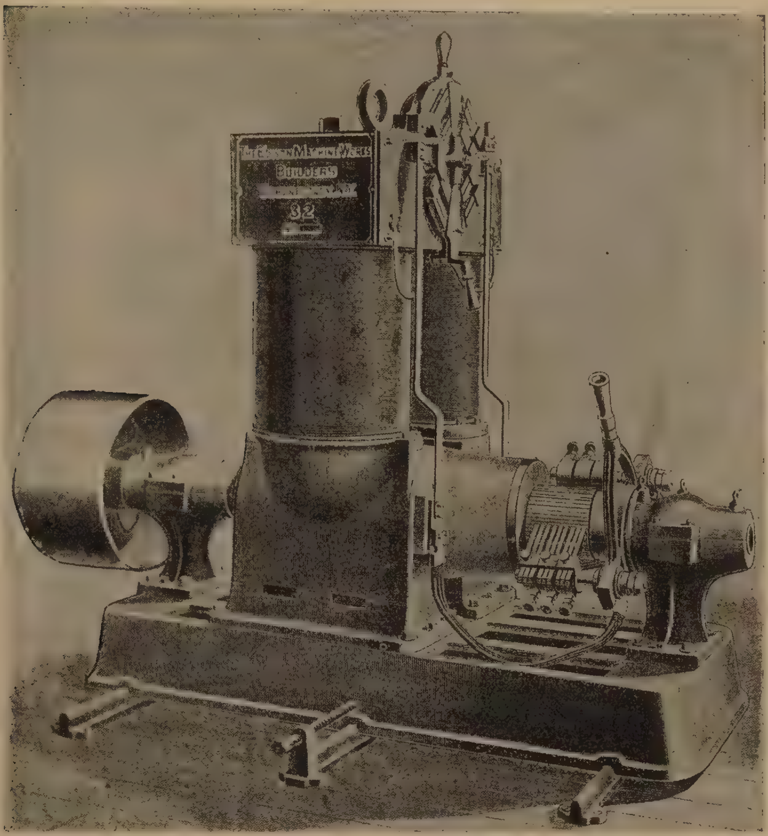


Fig. 5. Later Type of Edison Bipolar Dynamo

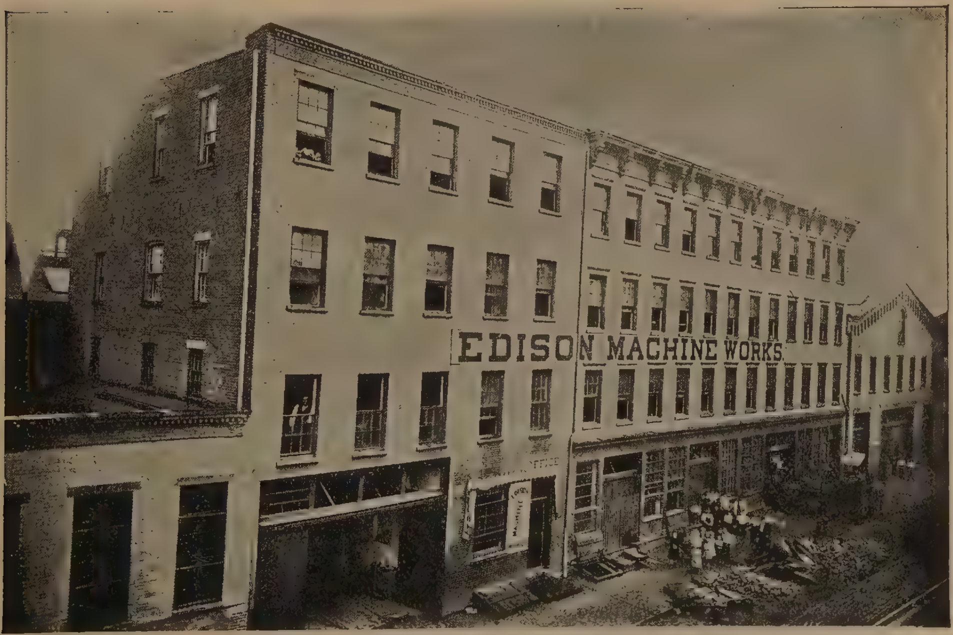


Fig. 6. Edison Machine Works, Goerck Street, New York City, March, 1881, to December, 1886

DATA ON OLD EDISON BIPOLAR DYNAMOS

Dynamo Symbols	H	Y	S	T	R	G
Number of 16-c-p. lamps	400	300	200	100	50	25
Revolutions per minute	1060	1120	1400	1500	1320	1465
Full load in amperes	406	276	180	93	45	23
Armature resistance (ohms)	0.013	0.0115	0.015	0.015	0.179	0.309
Field magnet resistance	8.25	9.24	7.17	14.25	19.135	26.45
Nominal e.m.f.	113	109	109	110	110	110
Length of armature	29⅜ in.	29⅜ in.	16½ in.	13 in.	10⅛ in.	10 ⅛ in.
Outside diameter of armature	10½ in.	10½ in.	10½ in.	8 in.	$5\frac{9}{16}$ in.	$5\frac{9}{16}$ in.
Outside diameter iron core	$9\frac{11}{16}$ in.	$9\frac{11}{16}$ in.	$9\frac{11}{16}$ in.	$7\frac{1}{16}$ in.	5	5
Size of wire	0.065 in.	0.134 in.	0.065 in.	0.042 in.	0.065 in.	0.042 in.
No. of loops	1	1	1	2	9	10
No. of wires per loop	16	4	12	10	2	3
No. of commutator blocks	44	48	54	60	22	22
No. of field magnets	3	1	2	1	1	1
Size of wire	0.065 in.	0.109 in.	0.058 in.	0.035 in.	0.042 in.	0.035 in.
Weight of wire on each core	65 lb.	85 lb.	65 lb.	25 lb.	41 lb.	25 lb.
Layers on each core	8	10	13	10½	10½	10½
Length of iron core	$25\frac{5}{16}$ in.	24 in.	20 in.	20½ in.	21½ in.	20½ in.
Diameter of iron core	7 in.	10½ in.	6¼ in.	5 in.	6¼ in.	5 in.
Turns per layer	312	175	220	384	310	384

From old notebook, written at Edison Machine Works, 104 Goerck Street, New York City.

ADDITIONAL DATA ON OLD BIPOLAR DYNAMOS

Dynamo Symbols	Z	L	K
Floor space	45 in. × 39 in.	60 in. × 39 in.	70 in. × 39 in.
Overall height	6 feet	6 ft. 6 in.	6 ft. 6 in.
Net weight complete	3000 lb.		8250 lb.
Diameter driving pulley	10 in.	14 in.	14 in.
Pulley face	6 in.	9 in.	9 in.
Revolutions per minute	1200	850	900
Horse power required	9	19	35

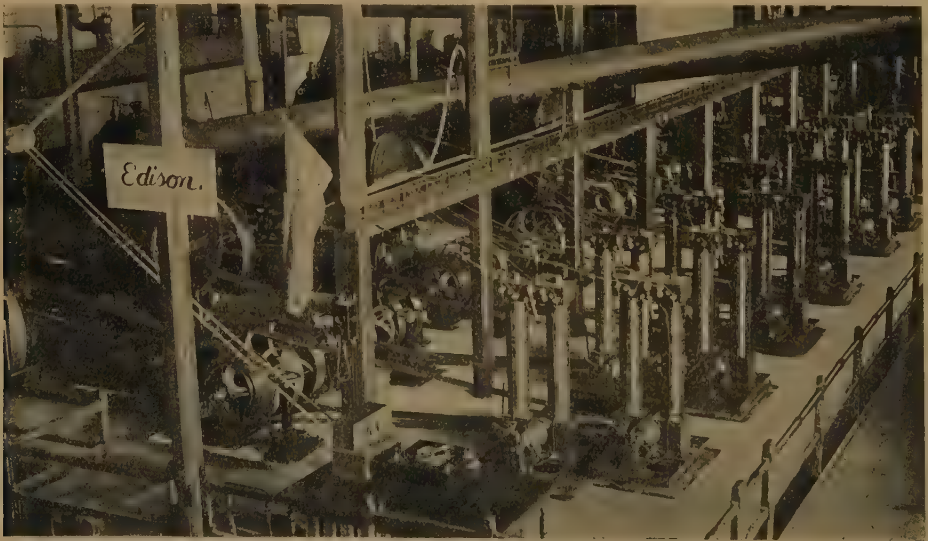


Fig. 7. "Z" Dynamos at Crystal Palace, Sydenham, England, 1882

Shaft Whipping

By Dr. B. L. Newkirk

Research Laboratory, General Electric Company

Vibrations and shaft whipping have proved very troublesome in the operation of some machines; often putting limits on their performance. Our article deals with an analysis of these disturbances and shows means and ways of prevention. We feel that this article is a valuable contribution to the technical literature on this important subject.—Editor.

Critical speed behavior of rotating shafts has been the subject of numerous theoretical discussions, and has caused much concern among designers and manufacturers of machinery.

A different but related phenomenon has appeared in the operation of certain machinery made by the General Electric Company. It affected a number of the smaller machines to a minor extent but the really serious trouble occurred in connection with the blast furnace compressors. These machines were subject to occasional fits of more or less violent vibration, the nature and cause of which were unknown. During these disturbances the shaft would vibrate at a low frequency which in some instances could be followed by the eye. The phenomenon was therefore called by shop men and engineers "shaft whipping."

The following article gives an account of the study that has been made recently of this matter. This study resulted in an analysis of the motion of the shaft, determination of the cause of the disturbance, and of means to overcome the trouble. A theory of the cause of the vibration proposed by Mr. A. L. Kimball, Jr., during the course of the investigation proved helpful in the solution of the problem. Mr. Kimball's theory with some revision and extension is published in the Appendix, page 178.

The whipping motion as observed casually appeared to be an oscillation of the shaft of rather low frequency, certainly much lower than the speed at which the shaft was running. This oscillation of the shaft set the whole machine into vibration. The phenomenon was known to occur only at speeds well above the critical speeds of the rotors in question. For example, rotors having critical speeds around 1000 r.p.m. would not whip at speeds below 2500 r.p.m., but the whipping might occur at any higher speed. The vibration was in some cases very gentle, so that it was scarcely noticed; in other cases the vibration was severe, necessitating the shutting down of the machine. No machine could be counted upon always to whip, or not to whip. Refinement of balance did not reduce this form of vibration. The whipping tendency seemed to depend upon conditions of temperature and humidity of the air. The steadiness of the blowing action was also an important factor; that is, with the compressor working against high furnace pressure, near the breakdown point of the machine, whipping was likely to occur, but it did not always appear under these conditions. The alignment of the machine and conditions at the bearings were known to influence the occurrence of this vibration. It was customary to adjust the ball-seated bearing liners with care, and special precautions were taken to prevent distortion of alignment of the machine by steam pipes or otherwise. When whipping occurred in spite of these and other precautions, it would usually be stopped temporarily by driving wedges at one point or another under the compressor foot to change slightly the alignment of the points of support. It was known that the fit of the impellers and packing sleeves on the shaft had much to do with the whipping tendencies of the rotor, any long sleeve gripping the shaft at the two ends of the sleeve being sure to produce whipping.

Analysis of the Motion

Our first effort was directed toward analysis of the motion. To this end two methods were employed, one of which has been in common use in our experimental study of vibrations for several years. A small coil with an iron core is imbedded in an iron block and the block is bolted in a position near the shaft, with the end of the coil $\frac{1}{16}$ inch (more or less) away from the shaft. A small direct current supplied by a battery is then passed through the coil, and any oscillation of the shaft, bringing it nearer to or further away from the coil, changes the magnetic flux and varies the current in the coil. This variation is recorded by an oscillograph. By using one of the three vibrators of the oscillograph for a timing wave and connecting the other two with coils opposite two points in the shaft the frequencies of vibration and the phase relation of the vibrations at the two points of the shaft are determined. *By this method we found that the whipping motion was a more or less regular whirl of the shaft and that it occurred at a constant frequency independent of the speed of the rotor. This frequency was identical with the frequency of the whirl at critical speed.*

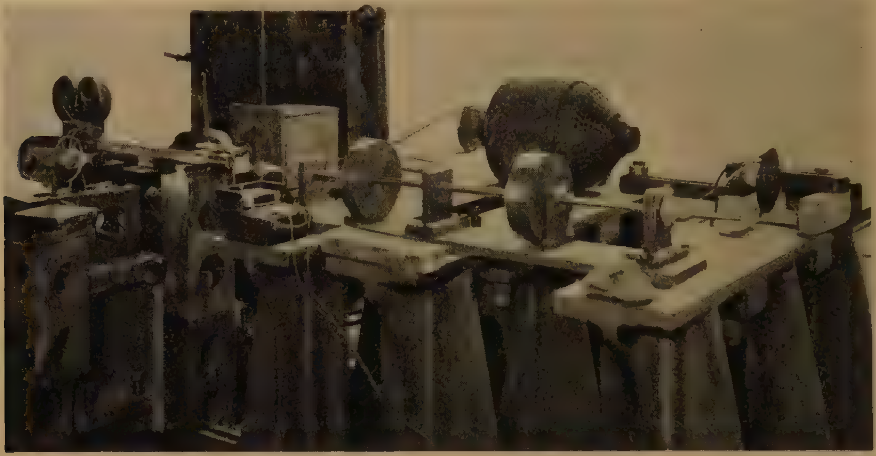


Fig. 1. Three-bearing Model Constructed for a Photographic Study of Shaft Whipping. An arc lamp at the left throws a beam of light on the pointed end of the motor-driven shaft; this illuminated shaft point is photographed by the motion picture camera, also at the left. Records of this character are shown in Figs. 3, 4 and 12

Another method of studying the motion is illustrated in Fig. 1. A pointer was attached to the end of a shaft. The tip of this pointer was illuminated by means of an arc lamp, and the motion of this tip was photographed with a motion picture camera making about sixteen exposures per second. This gave us a series of exposures each of about 1/36 of a second in length and with an interval of a little more than 1/36 of a second between exposures. Two of these photographs are shown in Figs. 3 and 4. These pictures brought out very clearly the fact that the whipping motion in the case of this model was a whirling nearly circular in form, occurring at a rate of about 2700 whirls per minute, and that this rate of whirling was independent of the speed at which the model was running. It should be noted that one of the critical speeds of the model is 2700 r.p.m. The tests just described were applied to other models and to three different compressors, and in all cases it appeared that the whipping motion was a whirling of the shaft, occurring with a period equal to that of the critical speed whirl of the rotor, and that the period of the whirling was independent of the speed at which the rotor was running. The statement that the whipping motion is always a whirl should be qualified by adding that irregularities were noted in the motion of the compressor rotors due presumably to the shock of pulsations of the air, and that extreme flexibility in the bearings in one direction (the horizontal for example) resulted in a motion that resembled plane vibration (in a vertical plane) rather more than a whirl. The period of the whirl-

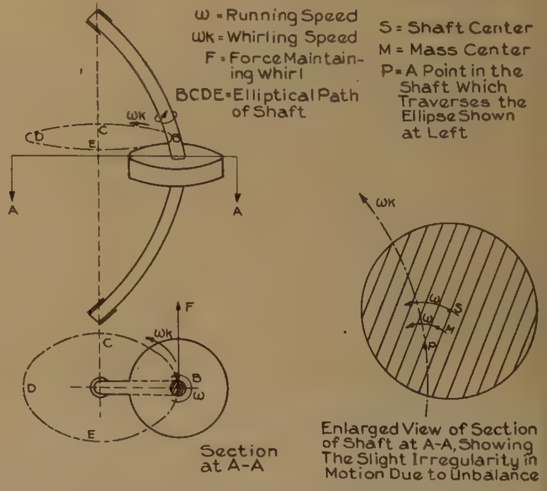

ω = Running Speed
ωk = Whirling Speed
F = Force Maintaining Whirl
BCDE = Elliptical Path of Shaft
S = Shaft Center
M = Mass Center
P = A Point in the Shaft Which Traverses the Ellipse Shown at Left
ωk
C
D
E
B
A
A
F
ω
S
M
P
Section at A-A
Enlarged View of Section of Shaft at A-A, Showing The Slight Irregularity in Motion Due to Unbalance

Fig. 2. Whipping is a Whirling Motion of the Shaft, shown in this Diagram in Greatly Exaggerated Form. The whirling speed is equal to the critical speed of the rotor and the running speed must be higher than the critical speed

ing was determined accurately by means of the oscillograph, as has been explained and the identity of the whirling period with the period of the critical speed whirl was established within narrow limits. It was also determined that the direction of the whirling agrees with the direction of rotation, as indicated in Fig. 2.

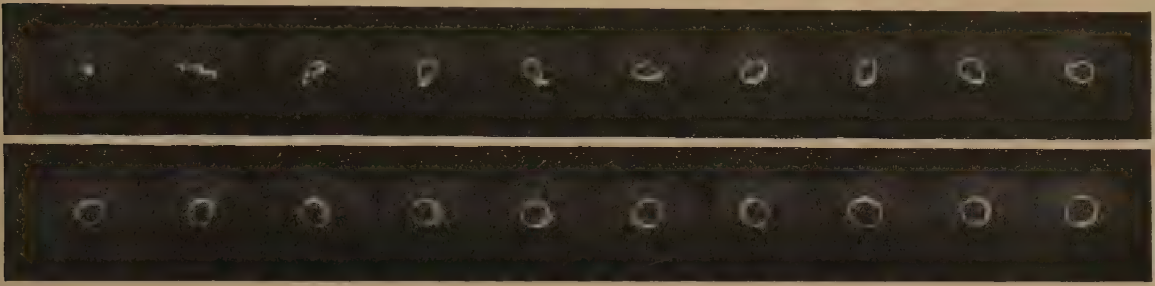


Fig. 3. Motion Picture Record of a Shaft Whipping Test Made on the Model shown in Fig. 1. The left-hand end of the lower strip joins on the right-hand end of the upper strip. The images trace the paths of the whirl during periods of about 1/36 sec. and succeed each other at about 1/36 sec. intervals. The whip is building up at 5000 r.p.m.

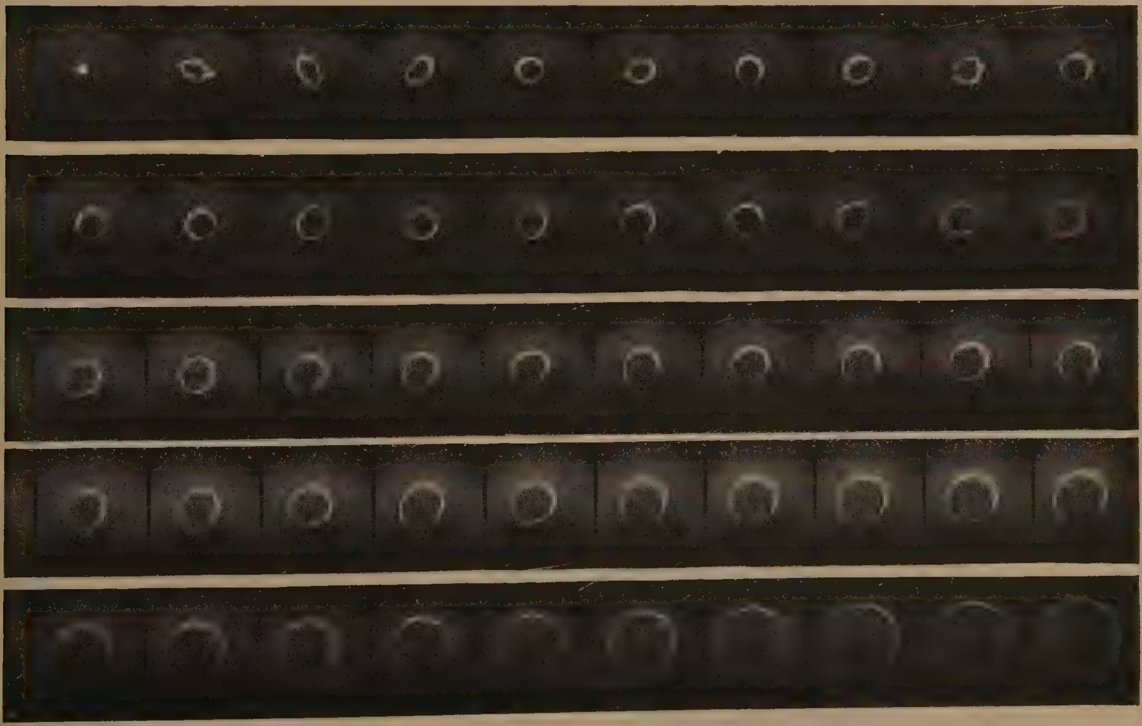


Fig. 4. Another Record Similar to that in Fig. 3 Except that it shows the Whip Building up at 6500 r.p.m.

It was then clear that the whipping motion of the shaft is approximately that indicated by the ordinary solution of the equations for the undamped motion of a shaft. For the convenience of those who may not be familiar with the literature of the subject, an outline of the solution is given in the Appendix, p. 178.

This follows the treatment given by August Föppl in the fourth volume of his technical mechanics.* It indicates that, neglecting damping action, a vertical shaft carrying one disk, such that the weight of the shaft can be neglected in comparison, may revolve as indicated in Fig. 2. This diagram shows a certain point P in the shaft traversing an ellipse at a certain constant angular velocity ω_K, while the shaft and disk are rotating about P at some other angular velocity ω. In the discussion of this solution, it is usually assumed that the whirling motion shown large in the figure (motion of P) is damped out quickly and that the superposed small whirling (about P) due to unbalance remains. Whipping then as we are using the term is a case in which the larger whirling does not damp out but builds up to the point where it is the major disturbance, and the effect of the unbalance is negligible in comparison. Presumably some force indicated by the arrow F in the figure acted to build up the motion. We observed that it built up gradually and that usually some jar was necessary to start it. We were inclined to the view that a jar was necessary to start the whipping in all cases and that in those cases in which the whip was apparently self starting, the small jars incident to running were responsible.

---

*See Vorlesungen über Technische Mechanik, Föppl, Vol. IV, 6th Ed., p. 281 (Tuebner).

Theory

At this stage of the investigation Mr. Kimball suggested that the internal viscosity of the metal of the shaft might furnish the stimulus for the whirling, and in support of this suggestion he presented the theory referred to. This theory as presented at that time was not altogether complete and convincing as to the mechanism by which the friction might produce the disturbing force F in Fig. 2. The following analysis was developed to determine more particularly how such a force might arise. It then appeared that cramping sleeves or impellers, etc., shrunk or pressed on the shaft produce an effect similar to that of internal friction of the shaft metal, and subsequent tests have shown that shaft cramping rather than internal friction of the metal of the shaft is responsible for the disturbance.

In this analysis, to avoid at first the complication due to the deflection of the rotor on account of its own weight, the shaft is assumed to be vertical and normal to the plane of the paper; also the rotor is assumed to be in perfect balance, since the component of the whipping motion which is due to unbalance is negligible as has been stated.

Let B (Fig. 5) represent the line of bearing centers, and suppose the shaft (represented in cross section by the circle) to be deflected due to some blow or other disturbance by the amount BO, to the position shown in the diagram. Let it be rotating with the velocity ω as indicated by the arrow. Then the shaft material in quadrants 1 and 2 is in compression, and the material in quadrants 3 and 4 is in tension. An element of the shaft in traversing quadrant 1 is becoming shorter, and in resisting this deformation it exerts a longitudinal force $C+$, where C is the purely elastic force, and the plus sign represents the additional resisting force due to the internal friction or to the friction of a cramping sleeve on the shaft. If a cramping sleeve or fit is the cause of whipping the friction is all at the surface of the shaft and is accompanied by some slipping between the shaft and the sleeve or hub, see Fig. 6. An element of the shaft in quadrant 2 is elongating, exerting a force $C-$, where C is again the purely elastic force, and the minus sign represents the decrease in this force due to a frictional force which opposes a change in length of the element. Corresponding effects occur in the case of elements in quadrants 3 and 4, the elastic resistance to deformation of the elements being augmented by the friction in quadrant 3 and reduced in quadrant 4.

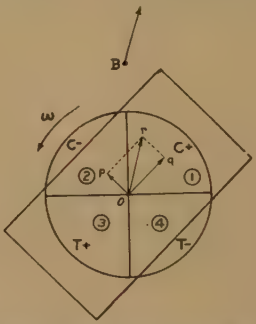


Fig. 5. Diagram Illustrating the Theory of Shaft Whipping. The circle represents the cross section (between bearings) of a rotating shaft deflected from the bearing center line indicated by the point *B*. Under these conditions the shaft assumes the elastic properties of a rectangular beam (shown in cross section by the rectangle)

As a consequence of these friction effects the forces which tend to restore the shaft to the straight condition, arising mainly from the bowed condition of the shaft, but modified by the friction as just described, are smaller in quadrants 2 and 4 than in quadrants 1 and 3, and the shaft when deflected *and rotating* has the elastic property of a rectangular beam, as shown in Fig. 5; that is, the component q of the total restoring force is greater than the component p. This is clearly the case since the components in the two planes of the deflection BO are equal, both having the value BO cos 45°. With equal deflection components and unequal stiffness in the two directions the greater restoring force is in the direction of greater stiffness. Combining the components p and q into their resultant r it is apparent that the shaft tends to spring back toward a point to the right of B. There would, of course, be a corresponding bearing reaction as indicated by the arrow at B. We have assumed that the deflection of the shaft from B to O was due to a blow or jar. This argument shows that during the short period while the shaft is in the sprung condition the restoring force r has a component (F in Fig. 2) at right angles to the line BO. This force starts the whirling motion which has been called whipping.

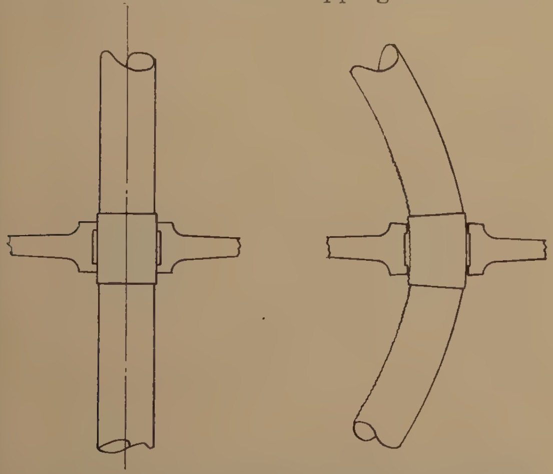


Fig. 6. Diagram Indicating the Cramping Action of Hub Fit when a Shaft is Deflected. Rotation of the deflected shaft causes alternate compression and stretching of each element of the shaft material as it passes from the concave to the convex side and back. When the deflection is large enough, local axial slipping takes place between shaft and hub

After the whirling motion has started that component of the restoring force r which is directed toward B balances the centrifugal force of the whirl, and the component normal to the line OB is the force F in Fig. 2 which maintains the whip.

When a shaft is whirling and rotating at the same time, as here contemplated, the rotation must be more rapid than the whirl, otherwise the force F (Fig. 2) necessary to maintain the whirl does not exist. If the rotation and the whirling are at an equal rate, one shaft element remains on the concave side and the friction effects just described do not occur. If the rotation is less rapid than the whirl a force corresponding to F in Fig. 2 develops, but in the opposite direction and the whirling then dies out rapidly.

In the preceding paragraph the shaft was assumed to be vertical in order to escape the complication due to the deflection of a horizontal shaft. Consider now the effect of the deflection, due to its own weight, of a horizontal shaft. This deflection should not start whipping provided the shaft is homogeneous and the cramping uniform about the circumference. The rotation of the deflected cramped shaft would of course modify the elastic restoring force of the shaft by introducing a component normal to the direction of the deflection as just explained. However, this would be a steady force and it would simply move the point O slightly to the right in the diagram (considering the shaft in Fig. 5 now to be horizontal) until the moment about the bearing centers of the weight of the rotor balances the moment of the force component due to the cramping. Equilibrium should then exist and the rotor should rotate without further variation of the deflection curve. Unless the rotor whips it should run quietly in this modified deflection curve. If now any jar or other disturbance superposes any other deflection of the cramped shaft in any direction, a corresponding force F, Fig. 2, develops and the shaft whips, not about the line of bearing centers as it does when the shaft is vertical, but about the deflection curve in which it would run if it were not whipping. Such disturbances will arise if the cramping is not uniform all around or if the shaft is not uniformly stiff in all directions at right angles to its axis, for under such circumstances its rotation would be accompanied by oscillations. Unbalance also might produce such oscillations.

The foregoing argument shows that when a vertical shaft runs true about its axis, there is no stimulus to whipping, due to cramping or internal friction since the deflection BO is zero. Some blow or other disturbance is necessary to produce a deflection and so initiate the whipping action. Once started the shaft whirls in an elliptical path, there is a deflection BO at each point of the path and the stimulating force F, in Fig. 2, is present. Similarly when a horizontal shaft rotates in its static deflection curve, slightly modified by the effect of cramping or internal friction as has been explained, equilibrium exists and there is no stimulus to whipping, but any disturbance brings the whipping stimulus into existence and the whirl occurs *about the curve in which the shaft would run quietly if it were not whipping.*

It should be noted that the expression "stimulus to whipping" as used throughout this article refers to the assumed force *F*, Fig. 2, and not to the blow or jar or other disturbance which this argument indicates should be necessary to produce a deflection, bringing the force *F* into play and initiating the whipping action.

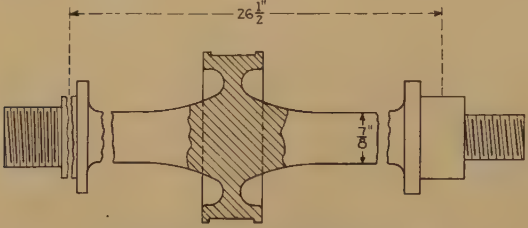


Fig. 7. Shaft with Special Hub Designed to be Free from the Cramping Action Illustrated in Fig. 6

As stated, it has been known for a long time in the Compressor Engineering Department that a "cramping fit" on the shaft would produce whipping. Further tests were made, therefore, to determine whether internal friction of the metal or cramping at a fit was responsible for the whipping of our models. A shaft was prepared of the section shown in Fig. 7, and a disk was mounted upon this shaft with a tight shrink fit. It was assumed that the unit stress (and consequently the deformation) in the metal of the shaft being very low where the hub is in contact with the disk, the tendency to slip between the shaft and the disk in this case would be less than the friction resistance to slipping, so that this stimulus to whipping would be eliminated, leaving the internal friction presumably the same as in other models. This particular model had a shaft ⅞ in. in diameter except at the hub, a span of 26½ in. between bearing centers and a disk weighing 85 lb. The bearings were SKF self-aligning No. 407. The critical speed was 1090 r.p.m. It was impossible to make this model whip, although it was run at nearly nine times its critical speed. To test the effect of a cramping fit in producing whipping a cramping device, shown in Fig. 8, was prepared. This is simply a collar with a chuck at each end to grip the shaft at two points about 7 in. apart. With this device the model whipped violently at all speeds above the critical speed. These and other tests convinced us that cramping fits rather than internal friction of the shaft metal are accountable for whipping.

We have found repeatedly in the course of our tests that any stimulus to vibration of the shaft which occurs in the frequency of the natural vibration of the shaft (that is, the frequency of the critical speed) will produce vibration of the shaft independently of the speed at which the rotor is running; which, of course, it should do according to theory. It is, therefore, not unlikely that whipping, by which is meant vibration or whirling at the critical frequency when the rotor is running at some other speed, may be and is sometimes produced by other causes than a cramping fit on the shaft. Our view at present is, however, that the difficulty with the blast furnace compressors has been due to the cramping fits.

We found that whipping produced in this way would not occur at speeds below the critical speed of the rotor. Where the tendency to whip was very strong as, for example, when the cramping device was used, the whipping would begin of its own accord when the rotor was running at any speed above the critical speed. The whipping could be quieted by steadying the shaft near the middle point, but as soon as the restraint was removed whipping would build up again until the shaft struck the guard. In other cases in which the tendency to whip was less pronounced, the rotor could be brought through the critical speed and would run quietly up to two or three times critical speed, and whipping would then begin of its own accord. In other cases in which the whipping tendency was still less pronounced, the whipping action would not begin of its own accord at any speed, but a sharp blow on the disk, producing deflection of the shaft, would start the whipping which would continue. In some cases the model would whip very gently without striking the guard, in other cases it

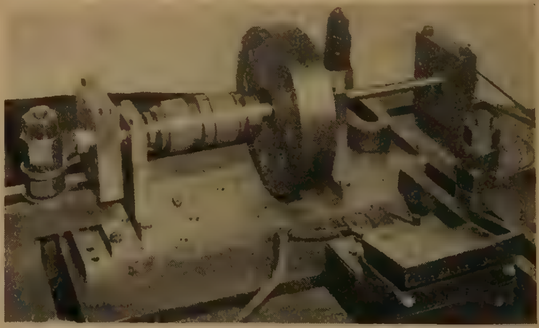


Fig. 8. Cramping Device on Shaft of Two-bearing Model Having One Flexible Bearing Standard (left)

would build up slowly until limited by the guard ring.

Means to Prevent the Whipping

Early in this investigation my assistant, Mr. H. D. Taylor, discovered that any looseness of the bearing standards, or of the clamps which held the model down to the iron floor in the factory where the tests were made, had a strong tendency to prevent whipping. It was found also that flexibility of the bearing supports tended to prevent whipping. An effort was made to decide whether flexibility only of the support would prevent whipping or whether some damping action was necessary in addition. To this end a holder, shown in Figs. 9 and 10, was prepared to take the place of one of the bearing standards and supply flexibility of the bearing with a minimum of damping frictional resistance to motion. It was found that, with a bearing supported in this holder, whipping would not occur provided the rod was clamped with sufficient free length. The required free length of the rod varies with different models, depending on the whipping tendencies of the model, but in general a free length of six or eight inches with a corresponding deflection at the bearing of 20 to 45 mils was sufficient to prevent the model from whipping.

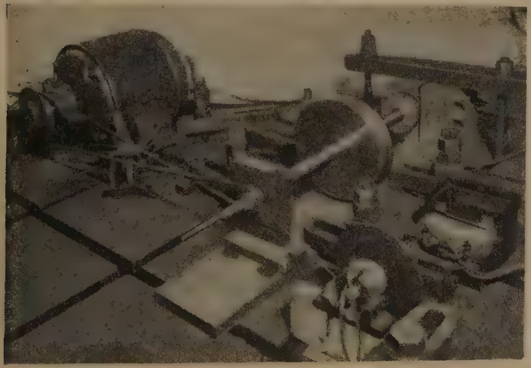


Fig. 9. Two-bearing Model Having One Bearing Flexibly Supported to Investigate the Effect of Such a Bearing on Shaft Whipping

As a consequence of this indication that flexibility of the bearing with or without damping resistance to vibration would prevent the whipping of models, spring bearings were prepared by Mr. W. E. Ver Planck, engineer in charge of compressor design, for several compressors. These were so made that an inner liner of the bearing was spring supported, and the designs included a device to introduce frictional resistance to any motion of the inner liner relative to the bearing standard. A series of tests was made with bearings of this sort at the compressor end of a three-bearing turbo-compressor rotor. In these tests heavy, light, and intermediate springs were tested, also frictional damping of different amounts. In no case could the compressor with a spring bearing be made to whip. It was found also that damping was not necessary except as it occurred incidentally in the operation of the spring bearing. Subsequent to these tests a number of machines in the field have been equipped with spring bearings at the compressor end and these are running without difficulty.

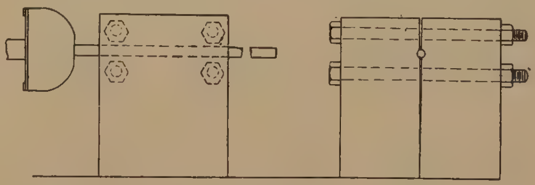


Fig. 10. Drawing of the Flexibly Supported Bearing shown at the Right in Fig. 9

It is perhaps difficult to accept the view that flexibility only of the bearing support, without any attendant damping or energy absorption in the bearing prevents whipping. This question cannot be put to a physical test, since with flexibility some motion occurs, and all motion is attended by more or less frictional resistance. The most careful tests, however, show that flexibility in the bearing with no more than the unavoidable damping, overcomes such stimuli to whipping as are found in our models or in the compressors.

While admitting that the unavoidable damping in any actual spring bearing tends to suppress the whip we must note also that the purely elastic characteristic acts in two ways to prevent and to suppress the whip. In the first place, according to the theory accompanying Fig. 5, some slight bend of the shaft over and above the deflection due to its load is requisite to initiate the whipping action. Such bend of the shaft would occur as a result of shock or jar. The spring bearing would yield under such shock and the spring supported shaft would bend less under any shock than it would if solidly supported. Thus the purely elastic action of the spring bearing reduces the initial stimulus to whipping.

In the second place we must assume that the whirling motion which we call whipping encounters an air resistance tending to damp it out. This resistance is undoubtedly larger the greater the amplitude of the whirl. When a shaft on spring supported bearings whirls with a given bend in the shaft the amplitude of whirl is greater on account of the yield at the bearing than it would be with the same bend in the shaft if the bearing were solid. Since the bend in the shaft determines the stimulus as has been explained, and the amplitude of whirl determines the resistance, the purely elastic effect of the spring bearing is to increase the resistance to whirling in comparison with the stimulus. This perhaps turns the balance in favor of the damping force. It is understood of course that the force F in Fig. 2 is very small indeed, and that the whip builds up or damps out like a resonant vibration, large amplitudes of motion resulting from a slight overbalance of the stimulus over the damping resistances. Thus the purely elastic action of the yielding support at the bearing acts both to reduce the initial stimulus to whipping and to suppress the motion if it should start.

The view has been expressed that the spring bearing does not stop the whipping motion of the shaft but acts as a cushion merely, to keep the vibration inside the machine. To one unacquainted with the facts disclosed by our investigation this view might seem reasonable. That it is entirely erroneous, however, is established by numerous tests, of which we have in many cases photographic records. Preparation for one of these tests is shown in Fig. 11. A pointer was fixed in the end of the shaft of a blast furnace compressor. The illuminated tip of the pointer was then observed with a microscope, and later photographed, while the compressor was made to pulsate in an effort to make the shaft whip. Since this pointer is an extension of the shaft any vibration of the shaft was easily detected by observing the tip of the pointer. Tests were run with solid bearings and then with a spring bearing at the compressor end of the unit. In the spring bearing we tried hard, medium and soft springs, also the use of damping friction in various degrees. The tests showed that with solid bearings this unit could be made to whip at will, but with the spring bearing it would not whip; also that so far as could be observed *no damping friction was necessary to prevent the whipping.*

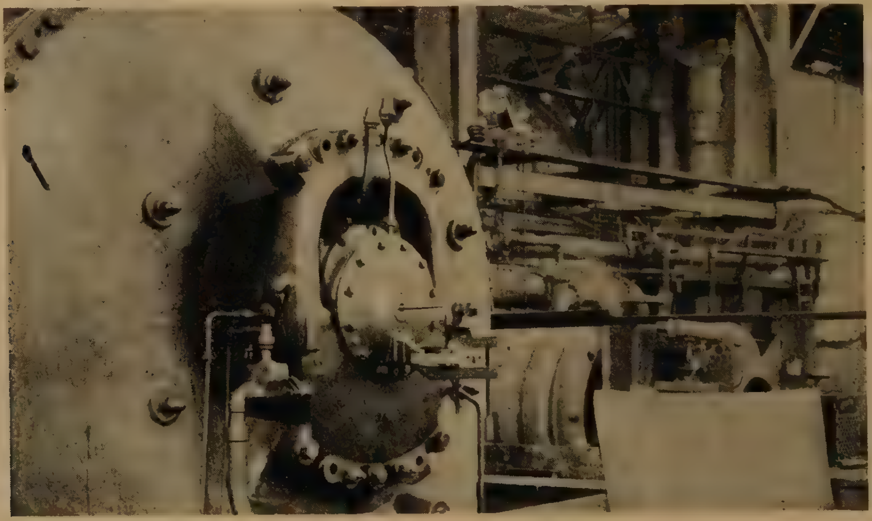


Fig. 11. Set-up That was Employed to Test a Centrifugal Compressor for Shaft Whipping

Fig. 12 shows a photograph of the pointer tip made with the special motion picture camera, modified to give about 4½ diameters enlargement. The interval between exposures is about $\frac{1}{16}$ second. Three jars due to pulsations are recorded on this strip of film. Not only did these jars fail to start whipping but *the shaft quieted down within* $\frac{1}{16}$ *second after each jar.* In this particular test *no damping friction was applied.* This and numerous related tests show beyond the shadow of a doubt that the spring bearing actually prevents the occurrence of the shaft whirl or vibration which has been called whipping.

In the light of this study of shaft whipping the occurrence and characteristics of whipping in blast furnace compressors as described in the first section of this article may be explained as follows: The belief that cramping sleeves or impeller hubs result in a tendency to whip was fully confirmed and explained. That the compressors would not whip at speeds lower than two or two and a half times the critical indicates that the whipping tendency in these rotors is not strong and that the stimulus, which in the case of the blast furnace compressors evidently increases with the speed, is not sufficient to maintain the whip at lower speeds. Variation in the degree of shaft cramping accounts for the fact that some machines whip more severely than others. Temperature conditions affect the alignment and tightness of joints in the compressor. Distortion of alignment by any other means affects the tightness of joints and the reactions at the supports of the compressor. These determine the frictional or damping resistance to vibration and so change the balance between the whipping tendency and the damping tendency as disclosed in the tests. The importance of conditions at the bearings was also confirmed by the tests, which showed that either looseness or flexibility at a bearing prevented whipping. That unsteadiness of the blowing action should precipitate whipping is to be expected, since such unsteadiness subjects the shaft to shocks due to turbulence of the air. Our tests indicated that a shock is certainly efficacious and probably necessary to start whipping. Driving wedges under the foot of the compressor stopped the whipping probably by distorting the machine or correcting a distortion, and so changing the flexibility at the bearing, or the minute working at the joints, thus giving the damping tendencies the preponderance over the stimulus to whipping.

Summary

A form of vibration which has proved troublesome in the operation of blast furnace compressors was analyzed and found to resemble the motion of a shaft as given by a well known solution of the differential equations of undamped shaft motion. The dominant motion in this case corresponds to the terms in the solution which are independent of the unbalance, which motion is usually assumed to disappear rapidly due to damping. A stimulus producing this motion was found to arise from a cramping of the shaft by sleeves or hubs which grip the shaft. It was found that in some cases this whirling would build up of its own accord, and that in other cases a shock was necessary to start it. It was found that the cause mentioned above would not build up a whirl or "whip" when the rotor was running below its critical speed, but that with sufficient cramping the whipping would build up with a rotor running at any speed above the critical. It was found that damping resistance to the vibration applied at any point along the shaft or at the bearings would suppress the whip; also that flexibility in the bearing supports with no more than the unavoidable damping incident to the flexibility of support would prevent whipping. Blast furnace compressors running with a spring bearing at the compressor end are free from whipping trouble.

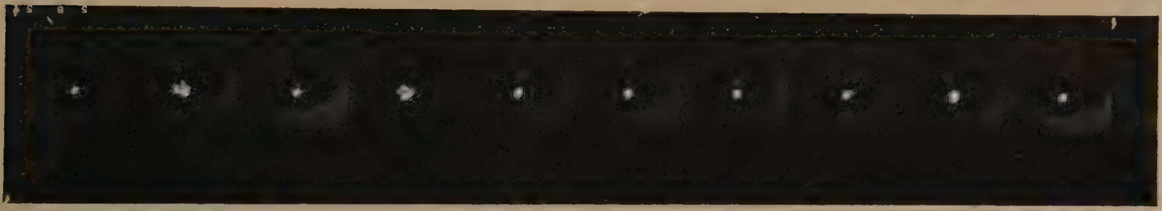


Fig. 12. Motion Picture Record of a Test Made on a Unit such as shown in Fig. 11 when a Spring Bearing was used at the Compressor End. The photograph shows three jars due to pulsation but no resultant whipping

This work was done at the request and with the active co-operation of Mr. W. E. Ver Planck, Designing Engineer, Compressor Section, Turbine Engineering Department. Rapid progress was made possible by the co-operation and interest of numerous members of the General Electric organization. Mr. Ver Planck's department made the tests of compressors, designing the necessary apparatus. The tests were run by Mr. S. R. Mensch whose interest and energetic conduct of the

work contributed much to its success. Dr. S. A. Moss of the Thomson Research Laboratory in the Lynn Works of the Company, followed the progress with interest, and made many valuable suggestions. The study of models was made in Schenectady by Mr. H. D. Taylor whose intelligent observation and interpretation of results were of great value. Mr. Kimball's theory as to the cause of the phenomenon has been referred to. This was a valued contribution to the solution of the problem.

APPENDIX

To avoid considering the effect of the weight of the rotor the shaft is assumed to be vertical. It is assumed also that the shaft is supported rigidly at two bearings. The plane of the paper is normal to the line of bearing centers, which line intersects the paper in O (Fig. 13). The shaft may be assumed to carry one disk, the mass of the shaft being neglected in comparison with that of the disk. Let S represent the center of gravity of the disk at any instant and A the shaft center at the same instant. The distance SA is represented by e, the value of which depends on the unbalance of the rotor. The coordinates of S are x and y and the coordinates of A referred to a parallel coordinate system with origin in S are p, q.

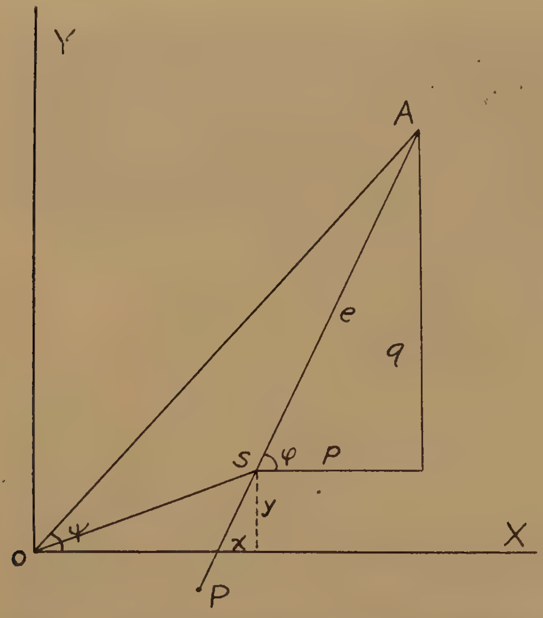


Fig. 13. Relative Positions of Shaft Center, Center of Gravity, and Line of Bearing Centers

It is assumed that shaft and disk rotate at uniform angular velocity ω, that is, that the angle ϕ increases at a uniform rate. This assumption excludes from the beginning consideration of any periodic torsional motion, or any irregular or spasmodic motion having a torsional component. Motion of the latter type did not appear in our photographs and does not seem to occur in ordinary shaft behavior. Its exclusion of this type of motion is certainly no serious objection to the assumption. The possibility of motion of the former type has been made the subject of careful consideration quite recently by Stodola and others. Their study, which is confirmed by tests, indicates that such periodic torsional motion builds up in an unbalanced horizontal shaft turning at half its critical speed, but not otherwise unless some special periodic stimulus is present. The assumption that our (vertical) shaft and disk run at uniform angular velocity probably corresponds very well with the facts, and the solution made on this basis gives a reasonably good picture of the motion observed in our tests.

We have, therefore

$$\phi = \omega t$$

$$p = e \cos \omega t$$

$$q = e \sin \omega t$$

$$m \frac{d^2x}{dt^2} = -c\,(\overline{OA} \cos \psi) = -c\,(x+p)$$

$$m \frac{d^2y}{dt^2} = -c\,(\overline{OA} \sin \psi) = -c\,(y+q)$$

where c is a constant depending on the stiffness of the shaft.

The general solution of these equations is

$$x = A \sin \omega_\kappa t + B \cos \omega_\kappa t + e\,\frac{\omega_\kappa^2}{\omega^2-\omega_\kappa^2} \cos \omega t$$

$$y = C \sin \omega_\kappa t + D \cos \omega_\kappa t + e\,\frac{\omega_\kappa^2}{\omega^2-\omega_\kappa^2} \sin \omega t$$

where ω_κ is a constant to be determined by substitution in the differential equations, and A, B, C, D are constants whose values depend on the position and velocity of the rotor at the instant it is left to itself. The value of ω_κ proves to be $\sqrt{c/m}$ which is independent of the other constants.

The motion of S may be analyzed into two motions as follows:

Let

$$x = x_1 + x_2,$$

where

$$x_1 = A \sin \omega_\kappa t + B \cos \omega_\kappa t$$

$$x_2 = e\,\frac{\omega_\kappa^2}{\omega^2-\omega_\kappa^2} \cos \omega t,$$

with corresponding expressions for y. The motion defined by x_2 and y_2 is in a circle at uniform angular velocity ω. The motion defined by x_1, y_1 is in an ellipse with angular velocity ω_κ. The point S, which is the center of gravity of the disk, moves therefore on a circle whose center moves on an ellipse, the center of the ellipse being at O.

The motion is easily visualized by constructing the point (x_1, y_1) in the shaft which traverses the ellipse. Extend the line AS to P as shown in the diagram, so that

$$\frac{SP}{AS} = \frac{\omega_\kappa^2}{\omega^2-\omega_\kappa^2}.$$

Then P is the point (x_1, y_1); for since $AS = e$, the X and Y coordinates of P are respectively

$$x - \overline{SP} \cos \omega t = x - e\frac{\omega_\kappa^2}{\omega^2-\omega_\kappa^2} \cos \omega t = x - x_2$$

$$y - \overline{SP} \sin \omega t = y - e\frac{\omega_\kappa^2}{\omega^2-\omega_\kappa^2} \sin \omega t = y - y_2,$$

which are equal to x_1 and y_1 as defined above.

Otheograph Records of Steam and Electric Locomotives

By P. M. Gillilan

Railway Engineering Department, General Electric Company

Considerable interest has been manifested in the otheograph, especially by railroad engineers who have been studying for a number of years the effect of motive power and other rolling stock on the rail. The name of this instrument was coined from two Greek words, and is literally translated "thrust writer." As constructed for this initial installation, this device records graphically both the vertical and lateral deflection of the rail as each successive wheel passes.—Editor.

During the exhibition tests at the Erie Works held December 4th and 5th, and recorded in the last issue of the Review, the practical application of the otheograph was demonstrated to the various railroad men present. Records were made of each of the many test runs and sample charts of representative runs are given in Figs. 2, 3, 4 and 5.

The otheograph is a device for recording the thrust on the rails by each separate wheel of a locomotive or motor car. This instrument shows by a graphic record the amplitude and characteristic of both the vertical and transverse thrust of all the wheels on each tie. The vertical deflection is transmitted through heavy springs underneath the rail and the transverse deflection through similar springs set vertically and bearing against the head of the rail. The deflection of these springs, as the locomotive passes, is recorded through a lever arm by means of a stylus which traces a record on a paper wrapped around a rotating cylinder similar to an engine indicator.

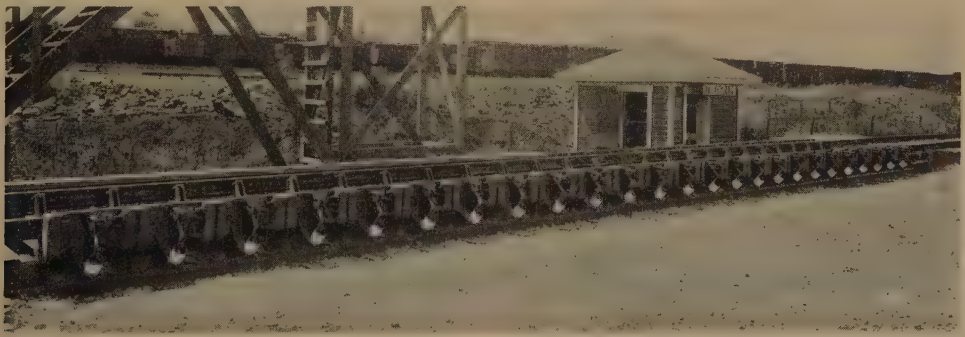


Fig. 1. Otheograph Installation of 25 Units showing Building in Background for Housing Driving Motor and Mechanism for Operating the Recording Drums

The otheograph ties may be installed in place of the regular ties, either singly or several together, and on curves or tangent tracks.

The record from a slowly moving locomotive shows the equalized distribution of the weight, and such a record serves as the basis for comparison with a record taken at high speed. The effect of side thrust in changing the vertical component, and any variations due to dynamic unbalance, are quite noticeable. The effect of a wheel with a flat spot will show clearly. The record is not necessarily limited to that of a locomotive, but by moving the paper slowly the record of all wheels of an entire train may be taken.

Particular attention has been given in the installation of these ties to obtain the same type of roadbed as the rest of the track. Each of the otheograph ties is located immediately over a wooden tie with the same supporting ballast as elsewhere. Between the otheograph tie and the wooden tie is a thin wooden stringer to retain the alignment, but with no appreciable vertical stiffness. The action of a locomotive running over these two seems to indicate that no unusual track condition is imposed.

The following typical test runs were made during the exhibition:

Number	
23.	Paris-Orleans electric locomotive—speed 105 m.p.h. east bound.
34.	Mexican electric locomotive with trailing passenger coach—speed 40 m.p.h. east bound.

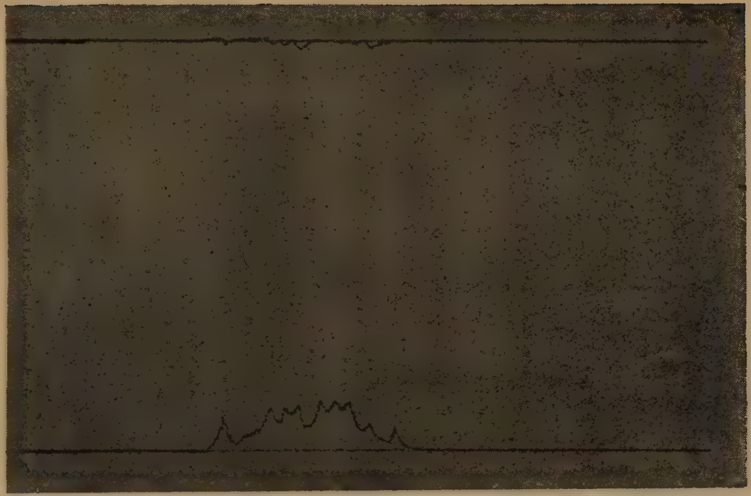
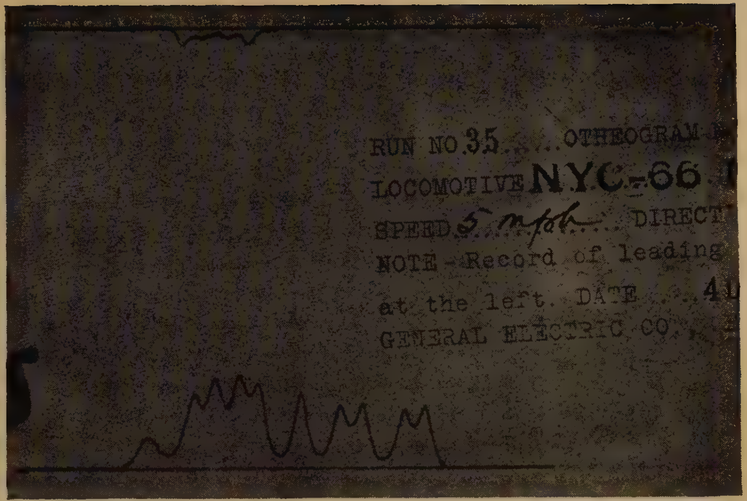
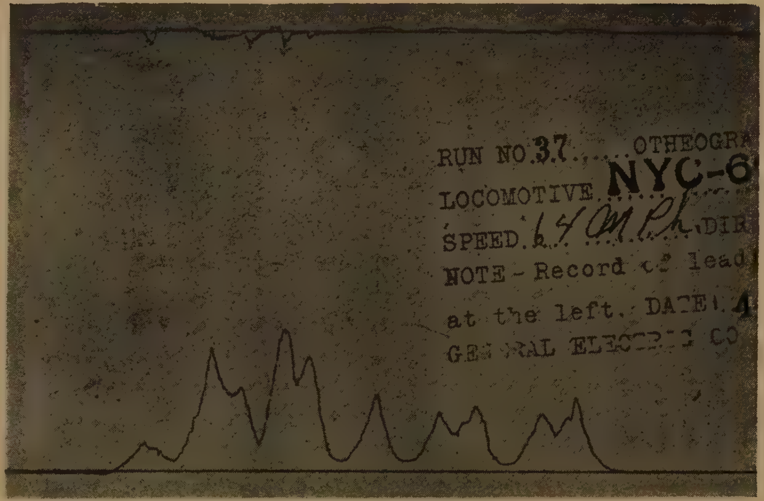


Fig. 2. Otheogram of Paris-Orleans Locomotive Running at 105-m.p.h. This locomotive is equipped with roller centering device on the guiding trucks to eliminate excessive lateral movement



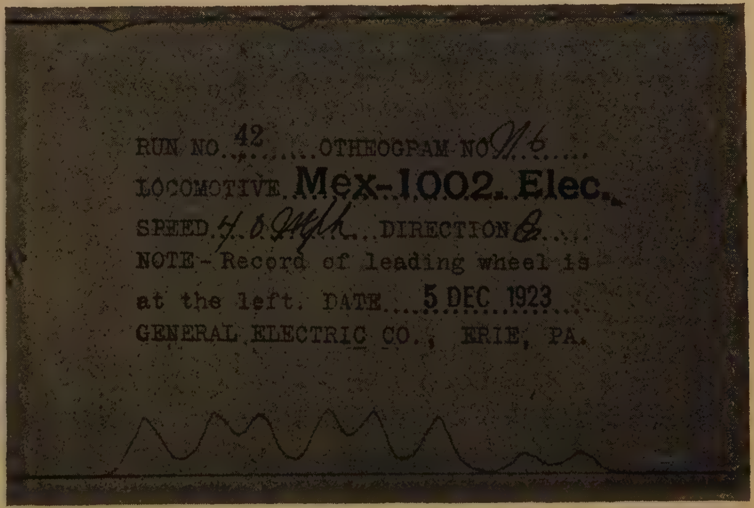
RUN NO 35 ..... OTHEOGRAM
LOCOMOTIVE NYC-66
SPEED 5 mph ..... DIRECT
NOTE - Record of leading
at the left. DATE ... 4
GENERAL ELECTRIC CO.,

Fig. 3. Typical Otheograph Record of New York Central Mikado Steam Locomotive (2-8-2) Running at 5 Miles Per Hour



RUN NO 37 ..... OTHEOGR
LOCOMOTIVE NYC-6
SPEED 64 mph DIR
NOTE - Record of lead
at the left. DATE 4
GENERAL ELECTRIC CO

Fig. 4 Typical Otheograph Record of New York Central Mikado Steam Locomotive (2-8-2) Running at 64 Miles Per Hour



RUN NO. 42 ..... OTHEOGRAM NO 116 .....
LOCOMOTIVE Mex-1002 Elec.
SPEED 40 mph ..... DIRECTION E .....
NOTE - Record of leading wheel is
at the left. DATE ..... 5 DEC 1923 .....
GENERAL ELECTRIC CO., ERIE, PA.

Fig. 5. Otheogram of Three-truck Electric Freight Locomotive, Mexican Railway Company, Limited, Running at Speed of 40 Miles Per Hour

35. New York Central Mikado steam locomotive—speed 5 m.p.h. east bound.
37. New York Central Mikado steam locomotive—speed 64 m.p.h. east bound.
39. New York Central Mikado steam locomotive—speed 70 m.p.h. east bound.
44. New York Central Mikado steam locomotive—speed 34 m.p.h. east bound and 30 m.p.h. west bound.
48. New York Central steam locomotive, Mexican electric locomotive and passenger coach. Steam locomotive pulling electric locomotive regenerating at 8.75 m.p.h.
49. New York Central Mikado steam locomotive, Mexican electric locomotive and passenger coach. Steam locomotive pulling electric locomotive regenerating at 15.5 m.p.h.
50. New York Central Mikado steam locomotive, Mexican electric locomotive and passenger coach. Steam locomotive pulling electric locomotive regenerating at 21 m.p.h.

These records were made during the test runs of the Paris-Orleans, the New York Central Mikado and the Mexican locomotives. Each set of 50 records was made simultaneously as the locomotive passed over the successive otheograph ties.

The otheograph installation comprises 25 ties grouped together covering a distance of 50 ft. of tangent track. The driving mechanism rotates all of the recording cylinders on both sides of the track simultaneously. This mechanism is driven by a constant speed motor with suitable gear reduction so that the distances between the peaks on the curves are proportional to the actual distance between the wheels on the various locomotives.

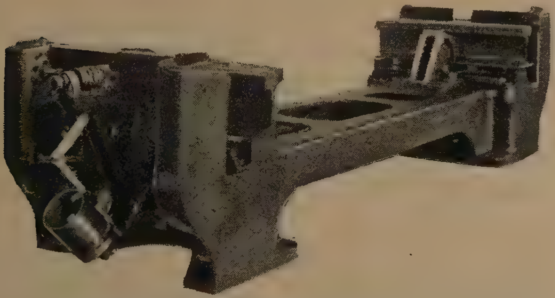


Fig. 6. Otheograph Tie with Rail Section in Place showing Recording Mechanism and Method of Securing Rail

Each record shows all the wheels of the locomotive and the direction of movement of the recording cylinder is such as to show at the left end of the record the deflection of the rail caused by the leading wheel. Each recording head indicates the vertical and lateral deflection of the rail as the successive wheels pass over the tie. The ties are numbered from west to east from 1 to 25. The prefix "N" or "S" indicates either the north or the south side of the track. In the construction of the roadbed there are three rail joints included in the group of otheograph ties, two of these being in the north side at "N3" and "N19" and in the south side at "S13."

Fig. 7. Pacific Type Steam Engine (4-6-2) Crossing Otheograph, showing Positions of Counterbalance and Crank Pins

The vertical deflection is recorded in the wave at the bottom of the chart, while the lateral deflection is shown at the top. All lateral thrust of the wheels outward from the center of the track is indicated by the record below the base line of the upper curve. It will be noted that the stylus needle shows a record above the zero line indicating a negative lateral movement. This is due to stressing the rail when the locomotive wheel is shifted toward the center of the track. Reference to the marks above the zero line will serve as an index to the lateral movement on the corresponding otheogram taken at the opposite end of the tie.

The amplitude of the records shows a multiplication of the movement of the rail of approximately 8 to 1. The amplitude or height of the record indicating vertical pressure is approximately 58,000 lb. per inch. The amplitude of the curve showing lateral movement is approximately 32,000 lb. per inch.

The Electrically Operated Flow Meter

By R. E. Woolley

Central Station Department, Meter Section, General Electric Company

The reasons that gave rise to the development of the electrically operated flow meter are presented in the introduction of the following article. Concerning them it may be mentioned that the new device is not intended to supersede the mechanically operated meter but to make available a second type, the choice between them being determined in each instance by the conditions existing at any particular location where a flow meter is to be installed. The field of usefulness of the new meter is outlined, and a description is given of the complete device, the function of its parts, and its general principle of operation.—Editor.

The widespread application of flow meters of the mechanically operated type, and the daily dependence placed on their readings, furnish ample evidence of the value of such meters in any line of business whose economical conduct depends on an accurate and continuous knowledge of the quantity of steam, air, water, oil, etc., flowing in pipes. Flow meters have been aptly termed "the eyes of the plant," and operation without them is blind.*

However valuable any meter may be as a device, its full measure of usefulness is not secured unless it can be arranged to display its reading at a convenient location. In this respect the installation of the mechanically operated flow meter has been handicapped in many instances. The logical place to tap the pipe is not always the desirable place to read the meter. Provided these two places are comparatively near each other, the mechanical meter has served the purpose completely and will continue to do so; but it is subject to the distance limitation factor of all mechanical indicating devices. For such conditions of plant layout, and also where it is desirable to read at some central location the flow in several widely separated pipes, a new type of meter has been developed.

In this new flow meter, the indication is transmitted electrically from the tapped pipe to the reading device, which method permits of a maximum degree of flexibility in installation. In addition to this primary feature, electrical transmission has enabled the development of a measuring device having no moving parts (except mercury) and the use of standard switchboard instruments to furnish the readings. These latter may be of an indicating, curve drawing, or integrating character, Fig. 1, and may be separated, grouped, or duplicated as will best suit the plant requirements.

Some Steam Flow Applications of the Meter

Measuring the total amount of steam generated by a single boiler or a battery of boilers.

Equalizing the load on individual boilers of a battery.

Discovering internal leaks in boilers shown by a difference in the water input and the steam output.

Determining when boilers need cleaning to remove scale, soot, etc., or if the method of stoking is satisfactory.

Measuring the amount of steam used for power or manufacturing processes.

Measuring the day-in and day-out steam consumed by turbines.

Discovering losses originating from leaks between boilers and points of consumption, e.g., defective traps, gaskets, and valves where the loss otherwise could not be detected.

Some Water Flow Applications of the Meter

Measuring the amount of feed water delivered to a boiler or battery of boilers.

Measuring the output of a pumping plant.

Measuring the total amount of water consumed by a municipality or the amount distributed to different sections.

Measuring raw or filtered water in a filtration plant.

Measuring the water input to water turbines and thereby furnishing a means for determining the wear of its parts without the expense and delay of dismantling the unit for examination.

Measuring the amount of water consumed in manufacturing processes.

Measuring the amount of cooling water used in condensers.

Measuring sewage in a sewage disposal plant.

Some Air, Oil, and Gas Flow Applications of the Meter

Measuring the total amount of air delivered to any department of a manufacturing plant.

Measuring the air delivered to mines for operation of machinery.

Determining the efficiency of compressors and different kinds of compressed air machinery.

Discovering losses originating from leaks between compressors and points of consumption due to defective valves, gaskets, or piping.

---

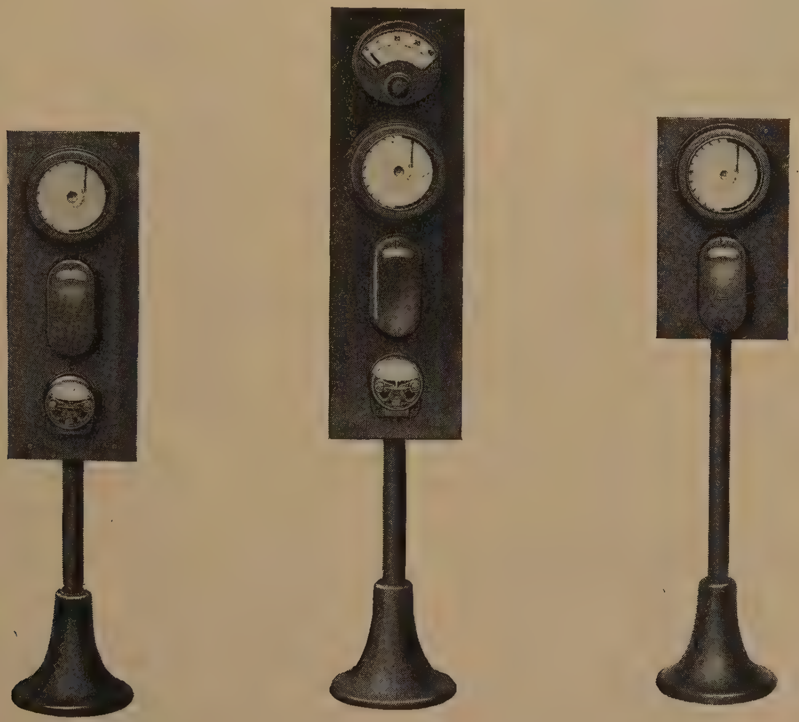
* See "Fuel Conservation in Industrial Power Plants," by David Moffat Myers, G. E. Review, Feb., 1922, p. 95.

Measuring the flow of heavy or light oils from wells, in pipe lines, etc.

Measuring the flow of natural gas, the output of producers, or the amount consumed by engines, furnaces, etc.

DESCRIPTION OF METER

The electrically operated flow meter consists of three principal elements: the flow nozzle which is installed in the pipe and which produces a differential pressure, the cast iron meter body which is piped to the flow nozzle, and the electrical measuring instruments which are mounted on the panel.


Curve Drawing and Integrating

Indicating, Curve Drawing, and Integrating

Curve Drawing

Fig. 1. Three of Thirteen Standard Combinations of Electrically Operated Flow Meter Instruments Mounted on Steel Panels

Flow Nozzle

The flow nozzle is illustrated in Fig. 2 and consists of a metal funnel or nozzle that is inserted between and held in place by the two flanges of a pipe. No nozzle plug or pitot tube is required. The shape of the approach portion has been so made that eddies and disturbances are reduced to a minimum in the throat portion, and both the approach and throat portions are carefully machined to dimensions. Steel is used in the construction of flow nozzles for measuring superheated steam while bronze is used for measuring water, air, oil, etc., and in some cases saturated steam.

The thickness of the walls and general design are such that the flow nozzle will withstand severe shocks without becoming distorted or going to pieces and damaging valves, machinery, etc. All nozzles used to measure steam have a drain hole to prevent the accumulation of water.

The various sizes of flow nozzles have been carefully tested to determine the law governing them and also the effect of elbows, valves, tees, etc., upon the accuracy of the readings.

Flow Meter

To illustrate the transformer principle employed in the electrically operated flow meter, consider a simple core-type transformer having a primary coil wound on one leg and a fiber cup surrounding the other leg as shown in Fig. 3. If the primary coil is excited by alternating current, the ammeter in series with this coil measures the excitation current required to supply the transformer losses. Now if mercury is poured into the fiber cup forming a ring around the laminations passing through its center, current will be induced in this mercury ring inversely proportional to its resistance if the primary resistance and magnetic leakage are neglected. The current flowing in the primary circuit and measured by the ammeter will necessarily be increased to supply the current in the mercury ring. As more and more mercury is poured into the fiber cup, the resistance of the mercury ring is decreased because its cross-section is increased and more and more current will be required in the primary circuit to supply that induced in the secondary mercury ring. It is therefore evident that the ammeter can be so calibrated as to measure the height of the mercury ring in the fiber cup.

Fig. 2. Flow Nozzle for Installation in a Pipe to Create the Differential of Pressure That Actuates the Flow Meter

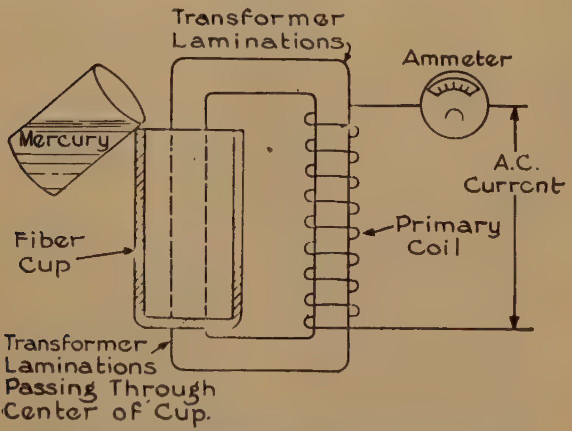


Fig. 3. Diagram Illustrating the Principle Employed in the Electrically Operated Flow Meter

Figs. 4 and 5 show the flow nozzle in the main pipe together with the flow meter body and instruments piped and wired to measure the flow of a gas or fluid in the pipe.

In the commercial form of the flow meter body a three-legged core-type transformer is used instead of a two-legged one as illustrated in Fig. 3. The primary coil is mounted on the middle leg of the laminations. The cast iron meter body containing the mercury and internal transformer is so made as to form a U-tube, Fig. 4; one leg is formed by the base or mercury well and the other by the smaller chamber in which the transformer is inserted. The base or large leg of the U-tube is connected to the upstream side of the flow nozzle and the small or transformer leg to the downstream side.

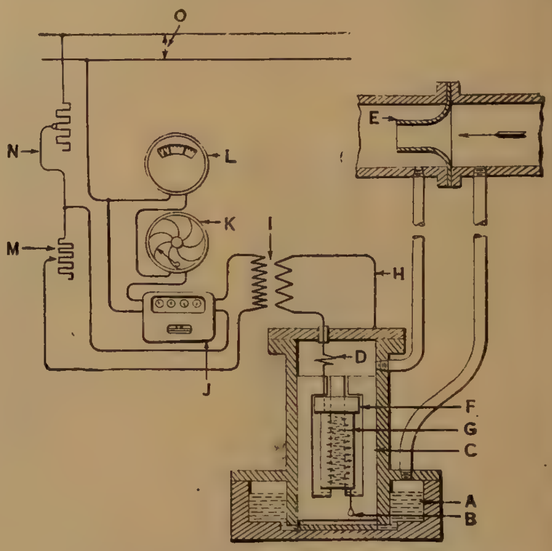


Fig. 4. Diagram Illustrating the Complete Electrically Operated Flow Meter with Piping and Wiring

A = Mercury
B = Ground connection of primary coil
C = Transformer laminations
D = Flexible rubber covered lead to primary coil
E = Flow nozzle producing a differential pressure
F = Insulating compound covering primary coil
G = Primary coil
H = Ground connection of transformer
I = Transformer mounted on meter body 108/5 volts
J = Watthour meter
K = Curve drawing ammeter
L = Indicating ammeter
M = Adjustable resistance compensating for line drop
N = Voltage regulator resistance in series with line
O = Alternating-current supply

On the outside of the meter body a small transformer, Fig. 5, is mounted whose function is to reduce the voltage applied to the internal transformer in the meter body as well as to act as an insulating transformer. A voltage of 108, held constant by the voltage regulator, is applied to the primary of this transformer while the secondary voltage applied to the primary coil of the transformer in the meter body is less than 5 volts.

In series with the primary of the outside transformer are the adjustable line resistance, voltage regulator resistance, and electrical measuring instruments.

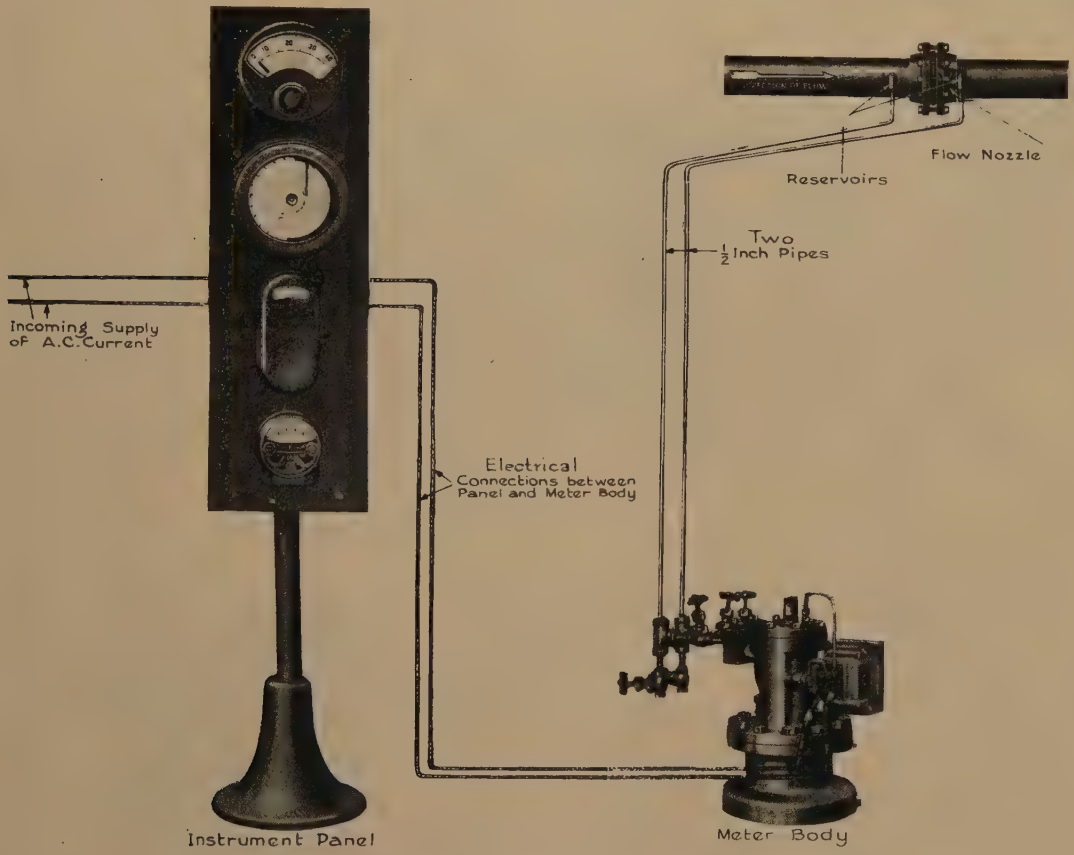


Fig. 5. Electrically Operated Flow Meter Layout Shown Diagrammatically in Fig. 4

PRINCIPLE OF OPERATION

When there is no flow of gas or fluid through the main pipe, the electrical instruments indicate the excitation current; and the zero readings on the instruments and meters are suppressed so that zero flow corresponds to this excitation current. When the gas or fluid flows through the pipe, there will be a differential pressure produced by the flow nozzle which causes the mercury in the meter body to rise in the transformer leg and fall in the base until the unbalanced column balances the differential pressure.

As this mercury ring rises around the primary coil of the internal transformer, more and more current is induced in it which must be supplied through the primary circuit, the action being similar to pouring mercury into the fiber cup as previously described.

By proper calibration the electrical instruments will accurately measure the height of mercury in the small leg of the U-tube containing the internal transformer, which height is a function of the flow of gas or fluid in the pipe.

Effect of Foreign Matter on Surface of Mercury

The inevitable accumulation in time of foreign matter, such as iron rust, pipe scale, etc., on the surface of the mercury in the meter body has no detrimental effect on the meter's operation unless it reaches such an amount as to stop up the pipes connecting the meter body to the flow nozzle. An accumulation in sufficient quantity to stop up these pipes will take years under ordinary conditions. No oil is used on top of the mercury.

DESCRIPTION OF VARIOUS PARTS

Internal Transformer

The internal transformer employs the three-legged core-type construction with the primary coil mounted on the middle leg as indicated in Fig. 4. The same transformer can be used on 60 and 50 cycles, but one having different electrical characteristics is required for 25 cycles.

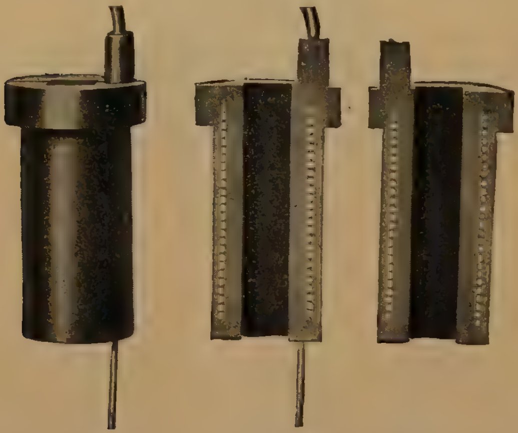


Fig. 6. Primary Coil of Internal Transformer Complete and in Section, showing Single-layer Winding Embedded in Insulating Compound

The primary coil, Fig. 6, consists of a single-layer winding moulded into an insulating compound. The bottom terminal of the coil is grounded to the circular iron plate clamping the laminations together at the bottom while the upper terminal is brought through the cover plate and sealed by a suitable stuffing gland. The voltage applied to this coil is so low (less than 5 volts) that the coil will not ground through the water filling the meter body even if the insulation is removed.

Body of the Meter

The body of the meter, Figs. 4 and 5, consists of an iron casting so designed as to form a U-tube, the base or mercury well forming one leg and the smaller chamber, in which the transformer is inserted, the other leg. The leg of the U-tube containing the transformer is slotted to a depth equivalent to the thickness of the outside leg of the transformer iron, so that when the transformer is in place the inner walls of the chamber form a cylinder.

Each meter body is supplied with equalizing, shut-off, and blowdown valves and piping between tees and equalizing valves.

Panels

The variety of panels to which the electrically operated flow meters may be connected are illustrated in Fig. 1 and are made of steel finished in dull black marine. By using steel instead of slate, the danger of breakage has been eliminated and weight materially reduced. The use of the pedestal base type of support for the panel permits the installation of single panels in corners and places where pipework, braces, etc., would be objectionable. In the grouping of panels either the pedestal base or pipework supports can be used.

Any of the indicating, curve drawing, integrating flow meters or accessories which are designed for steel panel mounting may as an alternative be mounted on slate or marble switchboard panels.

Indicating, Recording, and Integrating Flow Meters

The indicating flow meter is a round pattern ammeter having its scale calibrated in the proper units to indicate instantaneous values of steam, water, air, or gas flow.

The recording flow meter is a round pattern curve drawing ammeter which uses charts calibrated for the service required.

The integrating flow meter is a watthour meter giving the total flow of the gas or fluid being measured.

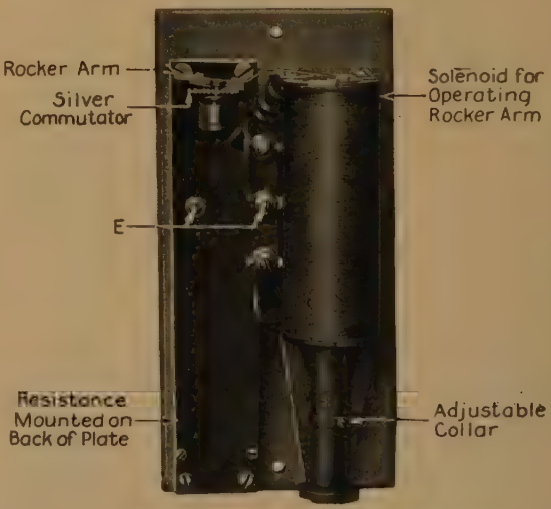

Rocker Arm
Silver Commutator
Solenoid for Operating Rocker Arm
E
Resistance Mounted on Back of Plate
Adjustable Collar

Fig. 7. Voltage Regulator for Individual Installations of Electrically Operated Flow Meters

Voltage Regulators

For accurate results it is necessary that the voltage of the supply circuit for electrically operated flow meters have a variation not to exceed one per cent plus or minus. This extreme refinement in regulation, rarely existing in the average feeder circuit, makes it desirable to regulate the voltage of the circuit supplying power directly to the meters.

When not more than 12 panels or sets of instruments are grouped together the type of regulator shown in Fig. 7 is used, one for each panel or set of instruments; but when more than 12 panels or sets of instruments are grouped, an automatic type regulator should be used, this latter having a capacity of 11 to 60 flow meter equipments.

the movable iron core is a rocker arm so shaped as to rock over silver commutator bars when the iron core moves up or down in the solenoid. Each of the silver commutator bars is connected with a resistance mounted on the back of the plate carrying the commutator in the same manner as the contacts on a rheostat, the resistance and rocker arm being connected in the circuit as shown at *N*, Fig. 4.

The initial setting of the regulator for various meter voltages between 110 and 125 volts is made by moving the adjustable collar up or down on the iron core.

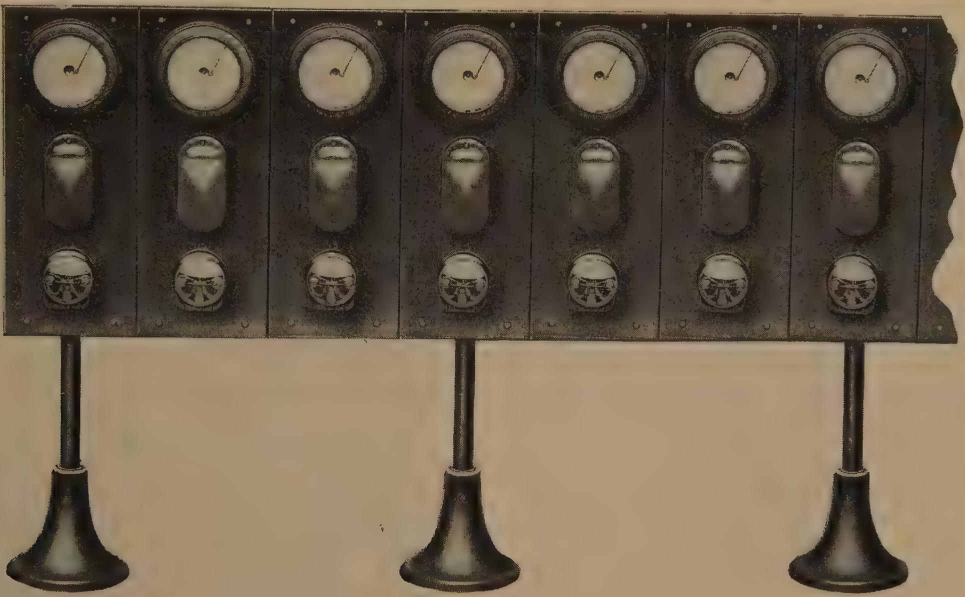


Fig. 8. A Group of Electrically Operated Flow Meter Panels on Pedestal Supports

Individual Voltage Regulator

The voltage regulator shown in Fig. 7 is very simple in design, and when properly adjusted will hold 108 volts on the flow meter circuit within a variation of less than one per cent plus or minus for a variation from 110 to 125 volts on the feeder circuit. If the feeder voltage is less than 110 volts it is necessary to install a small step-up transformer for increasing the voltage to some value between 110 and 125 volts as the regulator itself cannot raise the voltage of the meter circuit above that of the feeder circuit.

The regulator consists of a solenoid connected in multiple across the regulator flow meter circuit. Pivotly attached to the top of

The operation is as follows: if the voltage of the feeder circuit increases there is a momentary increase in voltage applied to the solenoid. This causes the iron core to rise and by means of the rocker arm and commutator more resistance is connected in the flow meter circuit, reducing the voltage to 108. On the other hand, if the voltage of the feeder circuit goes down there is a momentary decrease in voltage applied to the solenoid. This causes the iron core to fall, thereby reducing the resistance connected in the circuit and increasing the voltage to 108. The resistance between commutator bars being small, there is no injurious sparking or hunting.

Shaft Currents in Electric Machines

By P. L. ALGER
A-C. ENG. DEPT., GENERAL ELECTRIC COMPANY
and
H. W. SAMSON
DATA SECTION, GENERAL ELECTRIC COMPANY

In most cases the flow of current from shaft to bearings is of negligible consequence but those remaining cases where damage has been done have warranted investigation as to the cause of this phenomenon in order that the cause could be eliminated or the effects neutralized. The following article on the subject was presented as a paper before the Midwinter Convention of the A.I.E.E. at Philadelphia, February 4-8, 1924. The causes of shaft currents are defined, and the resulting actions analyzed and evaluated in turn. Of these, but one appears to be serious and in consequence it is given the greatest attention. The data and conclusions should be very helpful to the designing engineer.—EDITOR.

Introduction

A common source of trouble in revolving electric machines is the presence of electric currents flowing across the rubbing surfaces of the bearings. These currents make their presence known by blackening the oil, pitting the bearing, and, in extreme cases, scoring the shaft.

Figs. 1 and 2 show photographs of damage done to a shaft and bearings by these currents. Other photographs are given by Adler,[1] who states that currents greater than 1¼ amp. per sq. in. of bearing surface will damage the shaft, but that currents of lesser magnitude will harm the bearings only.

The usual type of shaft current flows in a circuit consisting of the shaft, the bearing pedestals or end shields, and the base. Interruption of this circuit by insulation under the pedestals, as shown in Fig. 3, is the most usual method of avoiding trouble from this source. In machines with end shield bearings, however, it is very inconvenient to insulate, and in no case does the use of insulated bearings afford any pleasure to either the manufacturer or the operator.

This article was written in order to present some ideas on the causes of shaft currents and methods of avoiding them. The published information on this subject is rather scattered, and, being chiefly in German periodicals, is relatively inaccessible to American readers; the previously established principles of the subject are also explained.

First the three possible causes of shaft currents will be described, then the two causes of minor importance will be briefly discussed, next the major cause will be carefully examined under two headings, then means for avoiding shaft currents will be explained, and finally a possible field of utility for shaft currents will be mentioned.

Possible Causes of Shaft Currents

All shaft currents are due to the existence of an e.m.f. between shaft and bearing lining. There are three imaginable ways in which such an e.m.f. can be produced:

(*a*) By a direct or alternating flux flowing in the shaft.

(*b*) By a difference of potential between shaft and ground due to electrostatic effects, or to grounding of the rotor conductors to the core.

(*c*) By an alternating flux linking the shaft.

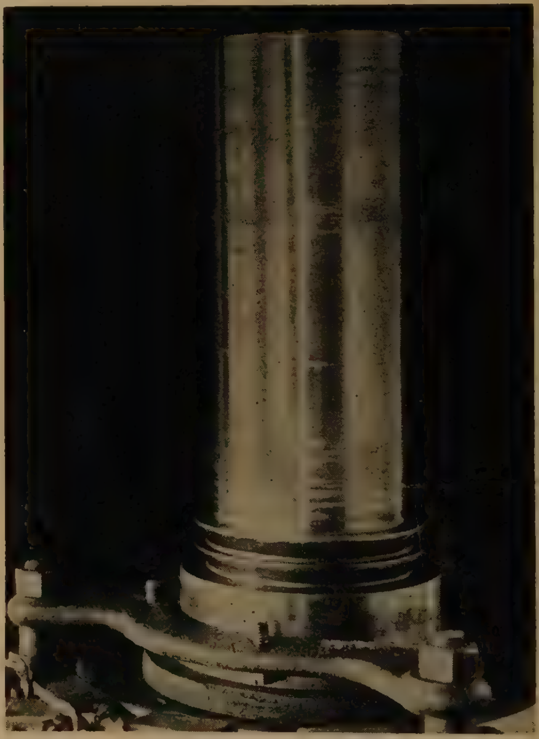


Fig. 1. Shaft of 500-h.p. Induction Motor showing Damage Caused by Shaft Currents

Of these (*c*) is by far the most important, and the one which has occupied the greater share of the attention of previous writers. However, in order to leave a clear field for the study of (*c*) once it has been started, the minor causes (*a*) and (*b*) will be first considered.

---

[1] Bibliography reference No. 6.

Shaft Currents of Type (*a*), Due to Shaft Flux

If, for any reason, a magnetic flux flows in the magnetic circuit consisting of shaft, bearings, and base of a machine, a homopolar voltage will be induced in each bearing due to the revolving shaft cutting the radial lines of flux passing from shaft to bearing. The voltages so induced in the two bearings will exactly neutralize, if the flux passing through one bearing is equal to the flux returning from the other bearing to the shaft. Hence such shaft voltages will chiefly cause local currents within the bearings, and insulation of the bearing pedestal from the frame will be of little use, except in so far as it increases the magnetic reluctance of the flux path. The most convenient paths for such currents to follow are from shaft to bearing through an oil ring placed at one end of the bearing and back from the bearing to the shaft through another oil ring placed at the other end of the bearing.

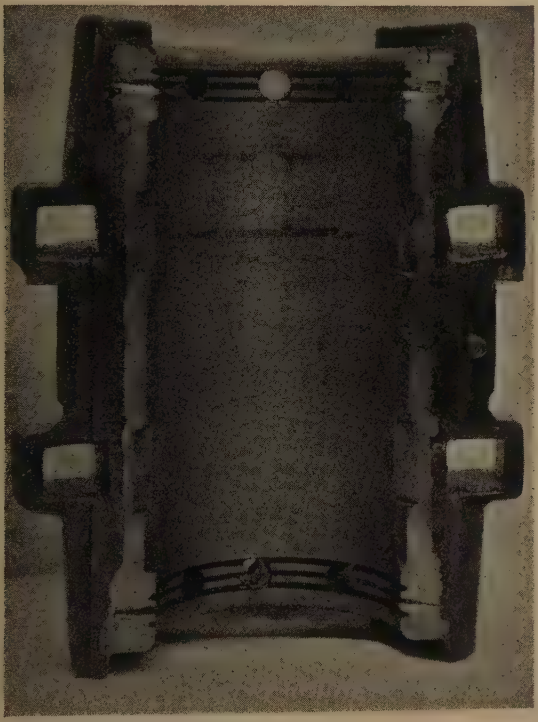


Fig. 2. Bearing of 500-h.p. Induction Motor showing Damage Caused by Shaft Currents

Whether the shaft flux is direct or alternating, a homopolar voltage will still be induced in the shaft, of the same frequency as the flux. Shaft fluxes will only appear as a result of a current linking the shaft. Only when an unsymmetrical construction of the windings is employed, such as sectionalized end rings for a squirrel cage, or a wave winding with only one bar per slot, will the multipolar machine be subject to this trouble. Homopolar machines, however, are likely to have considerable shaft flux.

An inspection of the developed two-circuit wave winding of Fig. 4 shows that the currents in the two circuits encircle the shaft in opposite directions, so that any inequality of these currents will give rise to a shaft flux.

A test was made on a large induction motor with such a winding on the rotor, to determine if appreciable shaft currents could be produced by shaft flux. One circuit of one phase of the two-circuit rotor wave winding was opened, and the motor was then operated under various starting and running conditions. Although under these conditions all the current of one phase of the rotor linked the shaft, it was ound that only a few millivolts were produced between shaft and bearings under the worst conditions. On disassembling the motor after these tests no signs of any shaft currents having been present could be detected.

There are other possible sources of shaft flux, such as uneven air gaps, and others listed by Buchanan.[2] No cases of shaft currents that could be proved due to these causes have come to the authors' attention, however, and it is their belief that the role of shaft fluxes in producing bearing trouble is a minor one. This belief is based on the experiment just described; and on the fact that insulation of the bearing pedestals is a generally accepted and successful remedy for shaft currents, although such insulation would not materially reduce homopolar shaft currents due to shaft fluxes.

Two methods are available for avoiding trouble from shaft flux, if such trouble is feared. One is the use of non-magnetic bearing pedestals, or the equivalent. The other is the use of a coil linking the shaft through which current is passed in such a direction as to counter-balance the existing m.m.f. available for making shaft flux.

Shaft Currents of Type (*b*), Due to a Potential Between Shaft and Ground

Electrostatic voltages between shaft and bearings may be set up by the friction of a belt or a pulley, or rubbing friction within the bearings themselves, or by reason of the potential of the rotor winding above ground.

---

[2] Bibliography reference No. 2.

Electrical men are familiar with the sparks which may be drawn from a revolving leather belt on a dry day, and with the severe jolt that may be received from touching the frame of an electric motor placed on wooden blocks. Such shocks are evidence of the potential that may be built up by electrostatic effects. It is conceivable that for such reasons as these the rotor of an electric machine may be brought to a potential considerably above ground, and that when the potential reaches a certain value it may discharge through the oil film of the bearing. Constant repetition of such sparks might conceivably in time give the usual pitting effects of shaft currents.

If one part of the rotor winding is accidentally grounded to the rotor core, the whole rotor will be raised above ground potential to the potential of this point of the winding, and so an e.m.f. between shaft and ground will result. If, in addition, the rotor circuit is grounded elsewhere, a short circuit will occur through the bearings. An accident of this kind actually occurred in one instance, with the result that the shaft was badly scarred during the few moments that the power remained on.

No cases are known to the authors where shaft currents of this nature have given trouble except as the secondary results of accidents.

Shaft Currents of Type (*c*), Due to Alternating Voltages Induced in the Shaft

In every multipolar electric machine, the flux of each pole, after crossing the air gap, divides into two portions, one taking a clockwise and one a counter-clockwise path through the yoke. If, for any reason, the clockwise flux, R, is not equal to the counter-clockwise flux, L, the effect is the same as if their difference, $R-L$, flowed completely around the yoke. This circulating flux will link the shaft and, if it is alternating, will induce a voltage in the circuit composed of shaft, bearing pedestals, and base, causing a shaft current to flow. This type of shaft current is by far the most important, and the one which has occupied the greater share of the attention of previous writers. It is characterized by the approximate equality between the shaft current at standstill, with the secondary open-circuited and full alternating voltage impressed on the primary, and the shaft current in normal operation. Also, this type of shaft current is approximately the same at no-load as at full-load. These characteristics serve to prove that it is not due to the load current, the end turn reactance, or the mechanical arrangement of the end shields, as has been variously suggested. Consider for example, the classical case of a four-pole alternator with a stator built in two sections as shown in Fig. 5. At *A* and *C* the yoke flux passes through regions of much higher reluctance than at *B* and *D*. But pole *1* need not send its flux through *A*. On the contrary, it will send the major part of its flux through *B* to pole *2*, allowing pole *3* to similarly send the larger part of its flux through *D* to pole *4*. Thus the final distribution of flux gives a component linking the shaft, as shown by the sinuous curve of Fig. 5. As pole *1* will be of north polarity at one instant and of south polarity one half cycle later, the flux linking the shaft will alternate at line frequency and will cause a shaft current of the same frequency.

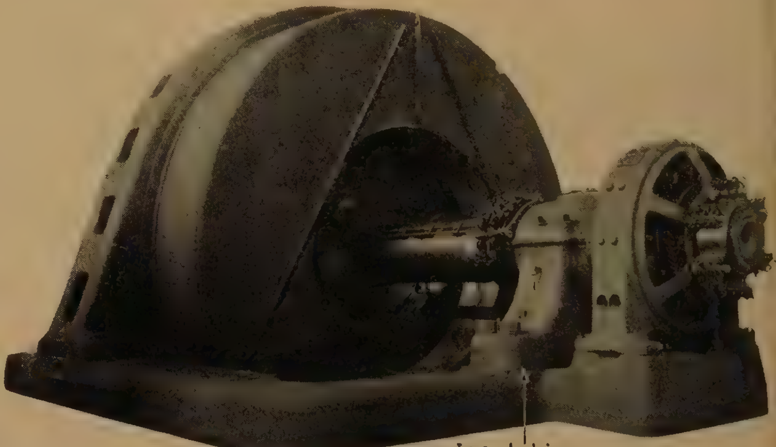


Fig. 3. Waterwheel-driven Generator (4000-kv-a., 6600/5400-volts) Having Insulated Bearing Pedestal

This subject of shaft voltages caused by the use of sectionalized stators has been very fully discussed by Fleishmann[3] and other writers, and reference to the articles listed in the bibliography will provide those interested with an over sufficiency of explanatory diagrams and discussions of the matter.

---

[3] Bibliography reference No. 8.

The general law which enables a prediction to be made as to whether any given sectionalizing of the stator will cause shaft currents with any given number of poles is:

(*1*) *Sectionalizing the stator will cause shaft currents if the ratio of twice the number of joints to the number of poles, expressed as a fraction reduced to its lowest terms, has an odd number for its numerator. The frequency of the shaft currents will be equal to this numerator times line frequency. If the numerator is an even number, no shaft currents will appear.*

For example, with 4 joints and 14 poles, the ratio reduces to 4/7, and as 4 is an even number, there are no shaft currents. With 2 joints and 8 poles, the ratio is 1/2, and line frequency shaft currents are set up. The foregoing rule applies only to machines with equally spaced and uniform joints. When the stator is divided into unequal sections special consideration must be given each particular case. In practically every case the joints between sections will vary enough to give some slight dissymmetry and, consequently, a small shaft current even though the numerator of the fraction "twice joints over poles" is an even number, but such accidental currents should not give serious trouble.

Sectionalizing the direct-current field of a synchronous or a direct-current machine will not cause shaft currents, since the flux linking the shaft will be unidirectional and constant.

Axial holes through the core for ventilation purposes, which are frequently used in high-speed machines, are another source of shaft currents, unless they are so located as to preserve perfect symmetry with respect to the poles. If the pattern of these holes is repeated every pole pitch, no shaft voltages will be produced; otherwise there will be. On the other hand, such axial holes may be so located as to partly neutralize the dissymmetries due to joints in the core, and so may be made to give beneficial effects.

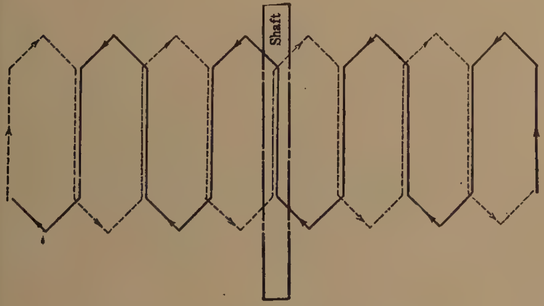


Fig. 4. Diagram Illustrating the Wave Winding Cause of Shaft Flux

The use of segmental punchings gives effects similar to sectionalizing. The joints in a segmental core are lap instead of butt joints, but they nevertheless have much higher reluctances than corresponding lengths of iron, and so they may cause marked variations between the reluctances of the parallel (clockwise and counter-clockwise) paths in the yoke. Tests have indicated that at 8 kilolines per sq. cm., one lap joint has a reluctance equal to about 25 cm. of yoke, while at densities of 12 and 15 kilolines, respectively, the equivalent lengths of yoke path are roughly 20 and 10 cm.

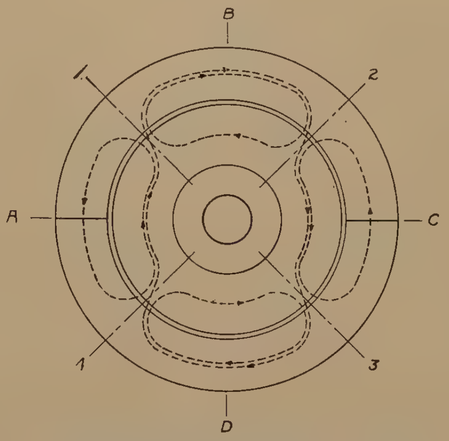


Fig. 5. Diagram Illustrating the Way in Which Shaft Voltages are Produced by Yoke Flux

It is the usual practice to provide each segmental punching with two symmetrically placed dovetails, and thus be able to assemble a core with twice as many (lap) joints as there are segments. Thus the use of any given number of segments has the same qualitative effects as the use of twice as many sections. Therefore Rule (1) previously stated also applies to the case of segmental construction. It may be restated as follows:

(*2*) *The use of symmetrical segmental punchings will cause shaft currents if four times the segments over the poles, expressed as a fraction reduced to its lowest terms, has an odd number for its numerator; and the frequency of the shaft currents will be equal to this numerator times line frequency.*

For example, an eight-pole six-segment stator will have three times line-frequency shaft currents, and a 30-pole 12-segment stator will have no shaft currents. The table of shaft current frequencies in Fig. 15 will be found useful in determining what combinations of joints (two times segments) and poles are most favorable.

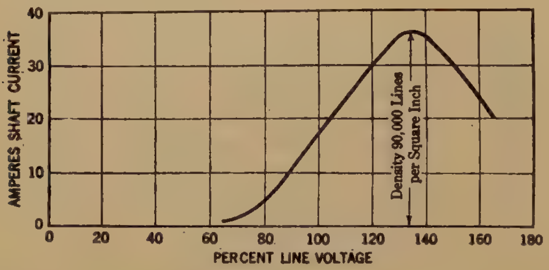


Fig. 6. Curve showing Variation of Shaft Current with Voltage

When the ratio of "four times segments to poles" is unity, all the poles share equally in the production of circulating flux and of shaft voltage. When this ratio is fractional, however, only a corresponding part of the poles contribute to the circulating flux, so that the greater the denominator of the fraction the lower will be the shaft voltage. Also, when the ratio is an odd integer greater than unity, the production of a shaft voltage is dependent on the presence of some degree of saturation in the yoke paths. For, referring to Fig. 7, which illustrates the flux paths in a motor having a ratio equal to three ($4 \times 6/8 = 3$), as adjacent joints in the yoke are spaced 120 electrical degrees apart, the algebraic sum of the fluxes passing through three consecutive joints is zero, assuming a sinusoidal distribution. If, therefore, the ampere-turns at each joint were proportional to the flux, the total ampere-turns introduced by the joints into the clockwise flux path would be exactly equal to the ampere-turns introduced into the counter-clockwise flux path, and no tendency for a circulating flux to appear would exist. Actually, however, the ampere-turns across each joint increase at a faster ratio than the flux, and so the two joints per pole in the clockwise flux path give less ampere-turns than the single joint per pole in the counter-clockwise path; a clockwise circulating flux being thus introduced.

In Fig. 6 a graph of a triple-frequency shaft current as a function of voltage is shown which illustrates the effect of saturation. At very low densities the ampere-turns across the joints are proportional to the flux, and at very high densities the entire yoke becomes so saturated that the reluctance of the entire flux path approaches that of air. In the first case the joint ampere-turns in the clockwise and counter-clockwise flux paths balance each other and in the second case the joint ampere-turns become negligibly small in comparison with the ampere-turns required for the remainder of the path; so that in both cases no circulating flux is produced. A very low value at reduced voltage is thus a characteristic of multiple-frequency shaft currents. Line-frequency shaft currents, on the other hand, are more nearly proportional to the voltage at low densities, and decrease less rapidly with saturation, as in these cases there are joints in only one of the flux paths.

When both rotor and stator of an induction motor are made with such a number of segments as to cause shaft currents, the resulting shaft voltage will be equal to the sum of the two shaft voltages that would be caused by the two sets of segments acting separately. The presence of rotor joints has very little influence on the effects of the stator joints, and vice versa. As the slip-frequency shaft voltages due to the rotor segments are small compared with the line-frequency voltages due to the stator segments, the rotor construction is of little importance in considering how to avoid shaft currents.

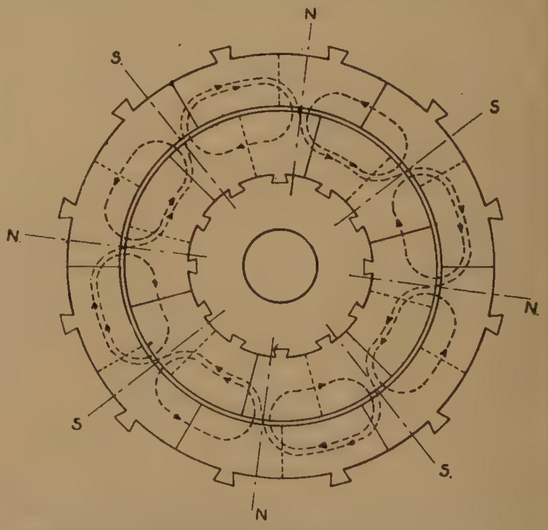


Fig. 7. Production of Shaft Voltage in an 8-pole, 6-segment Motor. One position for maximum clockwise flux

In order to obtain a clear idea of how a flux linking the shaft is set up in an induction motor with segmental rotor and stator, it is worth while to examine Figs. 7, 8 and 9. These show three positions of the rotor of an eight-pole motor with six segments in both rotor and stator. It is assumed that the slip is negligibly small, and so the center line of a north pole is in the same position on the rotor in each diagram.

Consider first the stator alone. In Fig. 7 the flux is in such a position that there is an excess of flux in the clockwise yoke paths, as the reluctance of the eight joints in series in the low-density regions of the core is less than the reluctance of the four joints in series in the regions of maximum core density. In Fig. 8 the flux has moved 1/24 of a revolution and now the counter-clockwise flux predominates. In Fig. 9 a revolution of 1/12 has been completed and the position is identical with Fig. 7. Thus the stator joints give a flux linking the shaft which completes 12 cycles per revolution, or gives three times line frequency.

Next consider the rotor alone. In all three diagrams the rotor joints give rise to a predominance of clockwise flux. If it is assumed that the air-gap distribution of flux is not affected by the unequal division of flux in the stator yoke, it is evident that the effects of the rotor joints are not dependent on the stator joints. At a later moment of the slip-frequency cycle the rotor joints will give a predominance of counter-clockwise flux, and after one twelfth of a revolution of the flux with respect to the rotor the clockwise flux will again reach a maximum and a cycle of shaft-voltage variation due to the rotor segments will be completed.

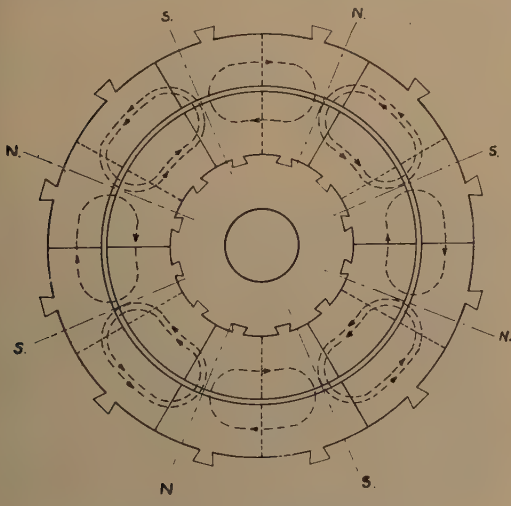


Fig. 8. Position for Zero Clockwise Flux, 1/24 Revolution Clockwise from Fig. 7

Figs. 7, 8 and 9 give a net resultant clockwise flux in the first position, zero flux in the second, and a clockwise flux again in the third position. But one third of a slip cycle later the three positions will give counter-clockwise, zero and counter-clockwise fluxes.

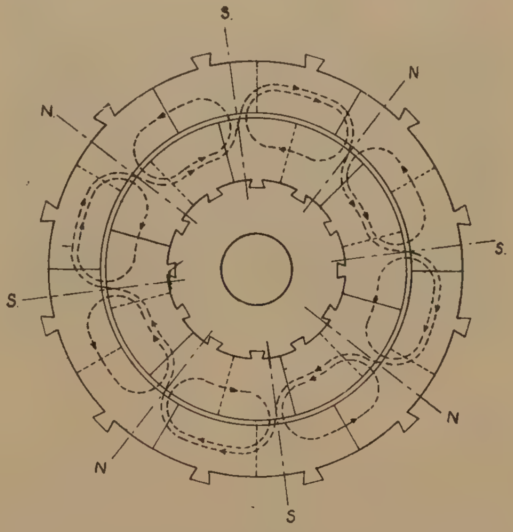


Fig. 9. Position for Maximum Clockwise Flux, 1/12 Revolution Clockwise from Fig. 7

Therefore, the 180-cycle shaft voltage due to the stator segments is simply superposed on the 180 times per cent slip-cycle voltage due to the motor segments and the magnitudes of each of the two voltages are the same as if they existed independently.

The shaft voltage shown in Fig. 10 was taken on a 16-pole motor with 12 segments in both rotor and stator. That shown in Fig. 11 was taken on an eight-pole motor with six stator segments and five rotor segments. In neither case is the shaft voltage due to the rotor segments (three times slip frequency in the first case and five times in the second case) large enough to be noticeable.

When an induction motor is at standstill, with open-circuit rotor, a shaft current due to the use of the same number of segments in both rotor and stator occurs at *n* times frequency instead of being composed of two different frequency voltages. But its magnitude then depends upon the rotor position, and it will vary through a complete cycle of values as the rotor is turned through an arc corresponding to one quarter of a segment. As the rotor accelerates the single-frequency shaft voltage breaks up into two components whose frequencies are at first near together and later separate more and more widely until, as full speed is reached, the shaft voltage consists of a large *n* times line-frequency component and a small *n* times slip-frequency component. Corresponding to these changes in the shaft voltage the shaft current will change its value in a seemingly erratic manner.

Fig. 10. Oscillogram of Shaft Voltage Across Ends of Shaft. Frequency, 150 cycles; line frequency, 50 cycles

It is a well known fact that the slip of almost any induction motor may be counted by observing the beats of a millivoltmeter placed across the ends of the shaft. The discussion given clearly shows that the beats of the millivoltmeter are due to a slip-frequency alternating flux encircling the shaft. And the widespread occurrence of this phenomenon shows that even very slight differences in the magnetic paths in the yoke will cause measurable shaft voltages. In many cases the ratio of "rotor segments to poles" is such as to give shaft voltages three or five times slip-frequency instead of slip-frequency itself. For this reason it is well to check the measured slip of an induction motor with a tachometer when the shaft voltage seems to give too high a frequency.

The two oscillograms of shaft currents shown in Figs. 10 and 11 pertain to induction motors with segmental stators having the ratio "four times segments over poles" equal to 3. In both these cases the oscillograms show the shaft voltages to be at three times line frequency thus verifying the Rule (2). The pulsations in the voltage in Fig. 10 are ascribed to tooth-frequency variations in the core flux. It is interesting to note that any third harmonics in the core flux of these machines will give shaft voltages of the same triple frequency that the fundamental flux does, as "four times poles over segments" for the third harmonic is 1 instead of 3, as for the fundamentals.

In Figs. 12 and 13 are shown oscillograms of shaft voltage taken on two turbine generators with one-piece stator frames. Since in both cases the ratio of "four times segments to poles" is an even integer, the rules previously laid down do not explain these shaft currents, except on the assumption that they are due to inequalities in the core joints. Evidently the fundamentals of these oscillograms are of line frequency, but the wave forms are extremely irregular. The reasons for these irregularities probably lie in the facts that the actual wave form of the alternator yoke flux is irregular, due to tooth pulsations, harmonics in the field flux, and saturation, and that the passage of this flux through so complicated a magnetic circuit as an annular steel core with irregular air gaps in it gives rise to a still more irregular m.m.f. wave form. If, however, all the joints in the cores had been uniform, no shaft current should have appeared no matter how irregular the flux wave form.

It is the resultant m.m.f. acting around the periphery of the yoke that causes the circulating flux which links the shaft, and this resultant m.m.f., being the difference between two relatively large quantities, has a wave form that is more irregular the smaller its average value. The shaft voltages shown in Figs. 12 and 13 were actually quite small, so that their poor wave forms cannot be taken as an indication that the wave forms of the yoke fluxes were anything like as irregular as they are.

In well designed machines all the important fluxes and currents should have closely sinusoidal wave forms, and so the wave forms of any large shaft voltages should be reasonably sinusoidal. Thus the excellent wave form shown in Fig. 11 is not entirely a matter of chance, but an indication of good design. This motor has nearly closed rotor slots and a good ratio of rotor to stator teeth so that only very small tooth-frequency pulsations

Fig. 11. Oscillogram of Shaft Current Across Ends of Shaft. Motor running light; frequency, 180 cycles; line frequency, 60 cycles

occur in the yoke fluxes. Also, the wave form of its exciting m.m.f. is very nearly sinusoidal, its gap permanence is very uniform, and none of the magnetic paths are too highly saturated. Consequently the wave form of its yoke m.m.f. should be very good, as the oscillogram actually indicates.

However, the irregularity of wave form of the three former shaft currents and the regularity of the latter are partly due to the differences in the voltage drops in the shaft circuit. In the turbine generator cases the voltage was taken from shaft to frame, so that the oscillograph current had to return through the other (inaccessible) bearing. In the induction motor cases the voltage was taken across the shaft through metallic brushes, so that the irregular voltage drop across the bearing was avoided. In taking Fig. 10 one brush was on the outside of the revolving shaft, making a rather irregular contact, while in taking Fig. 11 the contacts were made by axially-applied brushes on the two exposed ends of the shaft.

Remedies for Shaft Currents of Type (*c*)

Of course the first essentials in avoiding shaft currents are to banish the combinations of poles and joints indicated to be objectionable by Rules (1) and (2), or as tabulated in Fig. 15, and in every case to make the clearances between yoke joints as small and as uniform as possible.

Also, if the shaft and bearings are absolutely smooth and excessive speeds and bearing pressures are excluded, the oil films will act as effective insulators, and so damage to the bearings will be avoided. A large number of motors which are known to have triple-frequency voltages across the shaft of about one volt have been in successful operation for many years, so that small shaft currents are not necessarily dangerous. But any roughness on the shaft or excessive bearing pressure will cause rubbing, which will allow the currents to flow, and these currents will soon pit the bearings and so aggravate conditions as to in time destroy the bearing surfaces.

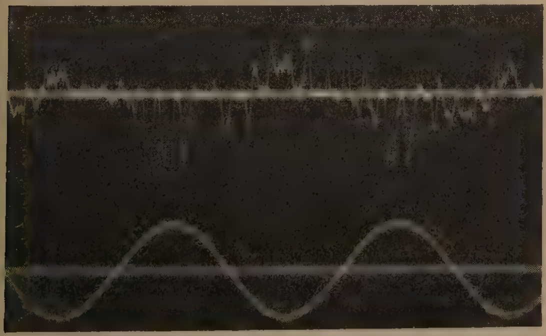


Fig. 12. Oscillogram of Voltage Shaft to Frame (upper curve). Lower curve; line voltage wave, no load

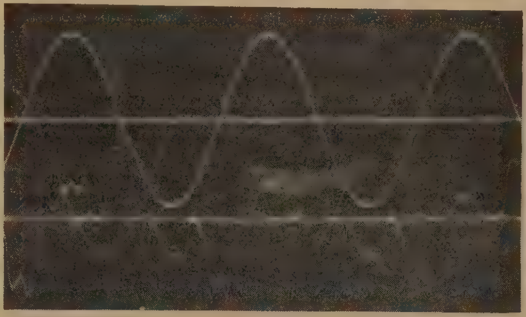


Fig. 13. Oscillogram of Shaft Voltage. Upper curve, phase 1-2. Middle curve, phase 1-3. Lower curve, shaft to frame

The end play of the shaft will usually give intermittent metallic contact from one end of the shaft to the bearing lining, so that the fact that the oil films in the two bearings are electrically in series is of no importance in lessening the currents. The end play explains the fact that frequently the voltage from shaft to ground will be zero on one end of the shaft and yet will be considerable on the other end. The presence of oil rings, which make metallic contact with the top of the shaft, affords a very convenient path for the shaft currents, and for this reason it will often be found that the first signs of bearing currents appear as scratches on the shaft under the oil rings. Thus permanent reliance can not always be placed on the oil film alone as an insulator.

The standard method of avoiding the effects of shaft currents is simply to insulate the bearing pedestals from the bed plate, or the bearing lining from the end shield. Such methods form the simplest way of getting around the difficulty, but they are difficult of adoption on machines with end shield bearings, and they are always a source of trouble and expense.

Several German patents describe other methods of avoiding these troubles. A common expedient is to place metallic brushes in contact with the ends of the shaft and connect them electrically to the frame, thus short-circuiting the bearings. But the contact drop of the brushes is so great that one third to one half the original current still flows through the bearings.[4] To improve this condition an A.E.G. scheme[5] proposes to connect the primary of a transformer across the brushes, the secondary being wound around the core of the machine. By proper arrangements the voltage applied across the brushes may be made to approximately oppose and cancel the line frequency component of the shaft voltage.

Another scheme[6] proposes the use of a ring-wound coil encircling the stator yoke, this coil being fed with a line-frequency current of such a phase angle as to most nearly cancel the ampere-turns set up by the joints. The current in this coil makes a circulating flux in the yoke which opposes the circulating flux set up by the dissymmetry of the magnetic circuit. This scheme affords a method of eliminating the ine-frequency component of the shaft voltage but does not avoid the higher frequency currents shown in the oscillograms, Figs. 12 and 13.

A third scheme[6] suggests the use of an iron collar encircling the shaft inside the bearings, which collar is wound with a ring winding. Application of a suitable line-frequency voltage to this coil sets up an alternating flux whose phase relation to the circulating flux in the yoke is adjusted to give the best cancellation. This scheme also completely cures the fundamental frequency component of the shaft voltage but does not remove the higher frequency components. None of the patented schemes mentioned would benefit in any way the higher frequency shaft currents such as shown in Figs. 10 and 11 and in fact the application would exaggerate the shaft currents in these cases.

Liwschitz[6] has suggested the cutting of a notch or notches in the yoke in such a way as to add reluctance in the yoke paths that have lower than average reluctance and so bring all the reluctances up to the same level. The simple cutting of such notches in the finished yoke would be very objectionable on account of increased core losses. But a better result can be simply obtained by making butt joints in the punchings to balance the butt joints between sections in those cases where the desirable number of sections is such as to cause bearing currents with the given number of poles. For example, a two-section four-pole motor would now be built with butt joints between sections and lap joints elsewhere, and so would have shaft currents. By making two extra butt joints in the punchings halfway between the section joints, all poles would be made alike and so shaft currents would be eliminated. This assumes that all the four-butt joints could be made very closely alike.

Preferred Method of Avoiding Shaft Currents Due to Segments

The methods so far considered apply equally well to shaft currents due to sectional and segmental stators, but the methods involving the introduction of a bucking e.m.f. are of no use in the case of certain numbers of segments in both rotor and stator. If segments alone are the cause of trouble, as is most commonly the case, the best and altogether most desirable method of avoiding shaft currents is to use offset segments.

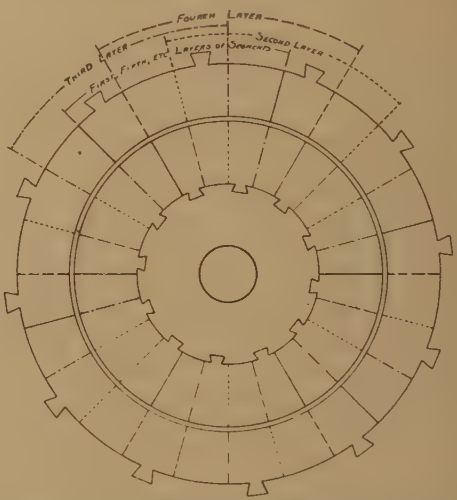


Fig. 14. Core Constructed with Offset Segments

For, if the segments are laid out as in Fig. 14 instead of as in Figs. 7, 8 and 9 with the dovetail tags (or notches) placed at the ⅛ and ⅝ points instead of the ¼ and ¾ points as is usually the case, the core can be built up with four joints per segment instead of two, and ¾ of the full iron section at each joint instead of only ½. This will be accomplished by laying any single pair of layers of punchings with lap joints in the usual way and then laying the next pair of layers upside down, so that the new lap joints come midway between the first lap joints, as shown in Fig. 14. It is not important that the dovetail tags come exactly at the ⅛ and ⅝ points, but it is essential that each tag come opposite a slot or a tooth, so that slots in the turned over punchings will coincide with those in the other punchings.

---

[4] Bibliography reference No. 6.

[5] Bibliography reference No. 5.

[6] Bibliography reference No. 5.

The usefulness of this scheme is somewhat limited by the fact that a blanking die with offset tags will seldom work with more than one number of slots per segment. If the tags are set at the ⅛ and ⅝ points, the number of slots per segment must be a multiple of 4, as 12, 16, 20 and 24. Thus one offset blanking die can be used with 20 and 24 teeth per segment but not with 21 and 22. But the scheme can be used with any combination die. And, the use of this construction will probably reduce the yoke ampere-turns and the core losses to a sufficient degree to make it worth considering for these reasons alone, regardless of the shaft current question. Transformer tests have shown that poorly made lap joints may increase the core loss by as much as 20 per cent, while at average densities each lap joint requires as many ampere-turns as 6 or 8 inches of the full-section part of the yoke.

Number of Equally Spaced Joints

Number of Poles

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	20	22	24	28	30	32	36	40	42	44	48	50	52	56	60	64	66	72
2	-	◇3	-	⑤	-	⑦	-	⑨	-	⑪	-	⑬	-	⑮	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	①	3	-	5	◇3	7	-	9	⑤	11	-	13	⑦	15	-	⑨	-	⑪	-	-	⑮	-	-	-	㉑	-	-	㉕	-	-	-	-	㉝	-
6	-	①	-	⑤	-	⑦	-	◇3	-	⑪	-	⑬	-	⑤	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	1	3	①	5	3	7	-	9	5	11	◇3	13	7	15	-	9	⑤	11	-	⑦	15	-	⑨	-	21	⑪	-	25	⑬	-	⑮	-	33	-
10	-	③	-	①	-	⑦	-	⑨	-	⑪	-	⑬	-	◇3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	①	1	-	5	①	7	-	3	⑤	11	-	13	⑦	5	-	◇3	-	⑪	-	-	⑤	-	-	-	⑦	-	-	㉕	-	-	-	-	⑪	-
14	-	③	-	⑤	-	①	-	⑨	-	⑪	-	⑬	-	⑮	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	1	3	1	5	3	7	①	9	5	11	3	13	7	15	-	9	5	11	◇3	7	15	-	9	⑤	21	11	-	25	13	⑦	15	-	33	⑨
18	-	①	-	⑤	-	⑦	-	①	-	⑪	-	⑬	-	⑤	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	①	3	-	1	③	7	-	9	①	11	-	13	⑦	3	-	⑨	-	⑪	-	-	◇3	-	-	-	㉑	-	-	⑤	-	-	-	-	㉝	-
22	-	③	-	⑤	-	⑦	-	⑨	-	①	-	⑬	-	⑮	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	1	1	①	5	1	7	-	3	5	11	①	13	7	5	-	3	⑤	11	-	⑦	5	-	◇3	-	7	⑪	-	25	⑬	-	⑤	-	11	-
26	-	③	-	⑤	-	⑦	-	⑨	-	⑪	-	①	-	⑮	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	①	3	-	5	③	1	-	9	⑤	11	-	13	①	15	-	⑨	-	⑪	-	-	⑮	-	-	-	◇3	-	-	㉕	-	-	-	-	㉝	-
30	-	①	-	①	-	⑦	-	③	-	⑪	-	⑬	-	①	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-
32	1	3	1	5	3	7	1	9	5	11	3	13	7	15	①	9	5	11	3	7	15	-	9	5	21	11	◇3	25	13	7	15	-	33	9
34	-	③	-	⑤	-	⑦	-	⑨	-	⑪	-	⑬	-	⑮	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	①	1	-	5	①	7	-	1	⑤	11	-	13	⑦	5	-	①	-	⑪	-	-	⑤	-	-	-	⑦	-	-	㉕	-	-	-	-	⑪	-
38	-	③	-	⑤	-	⑦	-	⑨	-	⑪	-	⑬	-	⑮	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	1	3	①	1	3	7	-	9	1	11	③	13	7	3	-	9	①	11	-	⑦	3	-	⑨	-	21	⑪	-	5	⑬	-	◇3	-	33	-
42	-	①	-	⑤	-	①	-	③	-	⑪	-	⑬	-	⑤	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44	①	3	-	5	③	7	-	9	⑤	1	-	13	⑦	15	-	⑨	-	①	-	-	⑮	-	-	-	㉑	-	-	㉕	-	-	-	-	◇3	-
46	-	③	-	⑤	-	⑦	-	⑨	-	⑪	-	⑬	-	⑮	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
48	1	1	1	5	1	7	①	3	5	11	1	13	7	5	-	3	5	11	①	7	5	-	3	⑤	7	11	-	25	13	⑦	5	-	11	◇3
50	-	③	-	①	-	⑦	-	⑨	-	⑪	-	⑬	-	③	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
52	①	3	-	5	③	7	-	9	⑤	11	-	1	⑦	15	-	⑨	-	⑪	-	-	⑮	-	-	-	㉑	-	-	㉕	-	-	-	-	㉝	
56	1	3	①	5	3	1	-	9	5	11	③	13	1	15	-	9	⑤	11	-	①	15	-	⑨	-	3	⑪	-	25	⑬	-	⑮	-	33	
60	①	1	-	1	①	7	-	3	①	11	-	13	⑦	1	-	③	-	⑪	-	-	①	-	-	-	⑦	-	-	⑤	-	-	-	-	⑪	-
64	1	3	1	5	3	7	1	9	5	11	3	13	7	15	1	9	5	11	3	7	15	①	9	5	21	11	3	25	13	7	15	-	33	9
68	①	3	-	5	③	7	-	9	⑤	11	-	13	⑦	15	-	⑨	-	⑪	-	-	⑮	-	-	-	㉑	-	-	㉕	-	-	-		㉝	-
72	1	1	①	5	1	7	-	1	5	11	①	13	7	5	-	1	⑤	11	-	⑦	5	-	①	-	7	⑪	-	25	⑬	-	⑤		11	-
76	①	3	-	5	③	7	-	9	⑤	11	-	13	⑦	15	-	⑨	-	⑪	-	-	⑮	-	-	-	㉑	-	-	㉕	-	-	-		㉝	-
80	1	3	1	1	3	7	①	9	1	11	3	13	7	3	-	9	1	11	③	7	3	-	9	①	21	11	-	5	13	⑦	3	-	33	⑨
84	①	1	-	5	①	1	-	3	⑤	11	-	13	①	5	-	③	-	⑪	-	-	⑤	-	-	-	①	-	-	㉕	-	-	-	-	⑪	-
88	1	3	①	5	3	7	-	9	5	1	③	13	7	15	-	9	⑤	1	-	⑦	15	-	⑨	-	21	①	-	25	⑬	-	⑮	-	3	-
92	①	3	-	5	③	7	-	9	⑤	11	-	13	⑦	15	-	⑨	-	⑪	-	-	⑮	-	-	-	㉑	-	-	㉕	-	-	-	-	㉝	-
96	1	1	1	5	1	7	1	3	5	11	1	13	7	5	①	3	5	11	1	7	5	-	3	5	7	11	①	25	13	7	5	-	11	3
100	①	3	-	1	③	7	-	9	①	11	-	13	⑦	3	-	⑨	-	⑪	-	-	③	-	-	-	㉑	-	-	①	-	-	-	-	㉝	-
104	1	3	①	5	3	7	-	9	5	11	③	1	7	15	-	9	⑤	11	-	⑦	15	-	⑨	-	21	⑪	-	25	①	-	⑮	-	33	-
108	①	1	-	5	①	7	-	1	⑤	11	-	13	⑦	5	-	①	-	⑪	-	-	⑤	-	-	-	⑦	-	-	㉕	-	-	-	-	⑪	-
112	1	3	1	5	3	1	①	9	5	11	3	13	1	15	-	9	5	11	③	1	15	-	9	⑤	3	11	-	25	13	①	15	-	33	⑨
116	①	3	-	5	③	7	-	9	⑤	11	-	13	⑦	15	-	⑨	-	⑪	-	-	⑮	-	-	-	㉑	-	-	㉕	-	-	-	-	㉝	-
120	1	1	①	1	1	7	-	3	1	11	①	13	7	1	-	3	①	11	-	⑦	1	-	③	-	7	⑪	-	5	⑬	-	①	-	11	
124	①	3	-	5	③	7	-	9	⑤	11	-	13	⑦	15	-	⑨	-	⑪	-	-	⑮	-	-	-	㉑	-	-	㉕	-	-	-	-	㉝	

◇ Denotes combinations, seemingly the worst, where the above given ratio reduces to the odd integer 3. Shaft currents in each of these cases can be completely cured by offset segments.

○ Denotes all other cases given in this table that can be completely cured by offset segments.

Fig. 15. Table of Shaft Current Frequencies

In any revolving electric machine, if the ratio of two times joints to poles expressed as a fraction reduced to its lowest terms has an odd number, N, for its numerator, shaft currents of N times line frequency will occur. By line frequency is meant the frequency of the magnetic flux in the jointed element of the machine. This table gives the values of N for various combinations of poles and joints. Combinations with which no shaft currents occur are indicated by dashes.

A crude alternative to the use of offset segments is to punch ventilating holes in the primary yoke in such a way as to create additional reluctances midway between the joints. These additional reluctances will offset the joint reluctances and so approximate the effect desired. This scheme of course increases the core loss and the yoke ampere-turns, and so is not recommended.

Turning Shaft Currents to a Useful Purpose

By constructing both stator and rotor of symmetrical segmental punchings with butt joints and considerable clearances, it would be readily possible to make a large part of the total yoke flux link the shaft. In this way shaft voltages could be produced equal to a fair percentage of the volts per turn in the main winding, and relatively large currents could be drawn from the shaft at low voltages and with fairly good wave form. By making $2\times\frac{\text{sections}}{\text{poles}}=1, 3$ or 5, frequencies of 1, 3 or 5 times line frequency could readily be produced. Of course the multiple frequencies would only be due to saturation and so this arrangement would be very inefficient indeed if used as a power-frequency transformer.

Thus a nearly standard induction motor construction could be used to produce large low-voltage single-phase currents at any frequency $(2m-1)$ times line frequency where m is any integer. Such a machine would have to deliver its current through brushes, and so would have some of the troubles of homopolar machines. Without proceeding to an extreme, an induction motor could be so constructed as to serve the dual purpose of rotating the shaft and also producing low-frequency currents. Of course, any such machine would have to have its bearings well insulated from the frame.

As previously noted, these shaft currents could be as well produced with the rotor stationary, and therefore the motor construction with bearings and air gap is entirely unnecessary, if the sole object is the production of these shaft currents. Such a machine would simply be a static transformer giving a secondary frequency 1, 3 or 5 times the primary frequency. If the frequency ratio is 1, the machine would be exactly equivalent to an ordinary transformer. If the secondary frequency is three or five times the primary frequency, due to proper choice of the segments, the machine is equivalent to a three or five-phase transformer of the usual type, with mesh-connected secondary.

These ideas on the utilization of shaft currents are rather fanciful, and it is not probable that they will be practically developed.

Conclusions

It is concluded that the most important cause of shaft currents is the presence of some dissymmetry in the magnetic circuits of the rotor or stator core, which causes more flux to flow in one of the two parallel (clockwise and counter-clockwise) paths than in the other, and so gives a resultant flux linking the shaft. The most prominent causes of such dissymmetries are sectionalized frames and segmental punchings. All cases where such divisions of the yoke will cause excessive bearing currents can be predicted by means of Rules (1) and (2). But the use of any sections or segments at all will give rise to some shaft voltages, due to the impossibility of making all joints exactly alike. These secondary shaft currents should not be harmful except in extremely high-speed machines like turbine alternators.

The most effective methods of remedying bearing currents, other than insulating, are to punch holes in the yoke in the regions of low reluctance, thus raising all parts of the yoke to the same level of reluctance, or to create a separate flux linking the shaft and opposed to the flux produced by dissymmetry or to make use of offset segmental punchings.

It is believed that the use of offset segmental punchings will effectively cure all ordinary cases of bearing currents in small induction motors, direct-current machines, converters, and synchronous motors and, as offsetting the dovetails gives better core loss, lower yoke reluctance, and a more solid core construction, with very little expense or trouble (once the new dies are developed), it is recommended that this scheme be adopted whenever practicable.

BIBLIOGRAPHY

1. Girault, Paul. On Currents in Dynamo Shafts. (In French) *Bulletin* de la Societe Internationale des Electriciens, Series 3, v. 5, pp. 127-63, Apr. 1, 1915. Same, abstract translation: *Science Abstracts*, Section B, v. 18, pp. 353-54.

Suggests modified theory of bearing currents due to sectionalized stators.

2. Buchanan, W. Currents in Bearings of Electric Generators. *Electrician*, London, v. 75, pp. 266-67, May 28, 1915.

Gives ample list of possible causes of bearing currents.

3. Merrick, E. G. Bearing Currents. *General Electric Review*, v. 17, pp. 936-41. October, 1914.

4. Arnold, E., and Lacour. Bearing Currents. (In German.) In their *Die Synchronen Wechselstrommaschinen*, 1913, v. 4, pp. 509-11.

Brief discussion of bearing currents due to sectionalized stator.

5. Liwschitz, M. Origin of Bearing Currents and their Prevention. (In German.) *Elektrotechnik und Maschinenbau*, v. 30, pp. 704-07, Aug. 25, 1912.

Very sound article on bearing currents giving several practical and effective methods of curing them.

6. Adler, L. Origin of Bearing Currents and their Avoidance. (In German.) *Elektrotechnik und Maschinenbau*, v. 28, pp. 157-64, Feb. 20, 1910. Same, abstract translation: *Electrician*, London, v. 65, pp. 314-17.

Discusses practical effects of bearing currents and shows photographs of damaged shafts and bearings.

7. Berger, L. Causes of Bearing Currents and their Elimination. (In French.) *La Lumiere Electrique*, v. 11, pp. 268-71, Aug. 27, 1910.

Mostly a review of the German investigations.

8. Fleishmann, L. Currents in Bearings and Shafts. (In German.) *Elecktrische Kraftbetriebe und Bahnen*, v. 7, pp. 352-53, June 23, 1909.

Originates theory of division of flux between parallel paths in yoke of sectionalized stator.

9. Punga, F., and Hess, W. Bearing Currents. (In German.) *Elektrotechnik und Maschinenbau*, v. 25, pp. 615-18, Aug. 11, 1907. Theory and tests. Same, abstract translation: *Science Abstracts*, v. 10, pp. 421-22.

Shows that a sectionalized stator causes bearing currents and gives data on the ampere-turns required to force flux across lap and butt joints in the punchings.

Studies in the Projection of Light

PART IX

THE HIGH-INTENSITY ARC AND THE PARABOLIC MIRROR

By Frank Benford

Physicist, Illuminating Engineering Laboratory, General Electric Company

The high-intensity arc described in this and a section to follow is so radically different from the plain carbon arc that special testing equipment and test methods were found necessary for its photometric analysis. The essential feature of the arc is a deep and well formed crater that is constantly filled with a highly luminous gas. The temperature of this gas is about 5500 deg. A. which marks one of the peaks of temperature attained by science. The distribution of brilliancy over the area of the crater is influenced by the depth of the contained gas and the angle of view, so that there is a wide departure from the disk source previously discussed, but the geometrical and graphical analysis of the ideal disk source is the foundation on which the analysis here presented is built. The methods are almost purely graphical but an interpretation of beam data depends largely on the geometrical relations given in former sections of this series. The effective range of the high-intensity searchlight is so great that there is some difficulty in making tests at the working range. The beam comes into final form rather slowly so that the test range is a matter of some importance and considerable attention is paid to a comparison of the short range distribution of light with that obtained at great distances.—Editor.

The High-intensity Arc

The discovery of the high-intensity arc some ten years ago marked the beginning of a new era in the history of the searchlight, and later developments indicate a widening range of usefulness for this arc that may ultimately include the entire motion picture industry and also many branches of the physical sciences that require light sources of intense brilliancy. The arc itself is in some of its characteristics so distinct from the pure carbon arc that a word of description may not be amiss. For the sake of definiteness, the 150-amp. arc will be described, and while each size of arc has its own peculiarities of operation a general description of one will be true for all.

The positive electrode of the 150-amp. arc is 16 mm. in diameter with a core of just half that size. The core contains a large percentage of the cerium fluoride obtained as a by-product in the manufacture of the Welsbach gas mantle. This core is very dense and hard and is inserted in the shell with a minimum of clearance. The shell itself is carbon of high purity formed under pressure and is exceedingly hard. The Brinell test shows a hardness greater than that of mild steel, and as might be expected the electrode is brittle and requires care in handling.

The negative electrode is of pure carbon throughout and has a hard shell 11 mm. in diameter and a soft core 3 mm. in diameter. The function of this core is to keep the arc centered. The core burns below the end of the shell and the sharp edge of the hole in the shell forms a fixed taking-off point for the arc.

The positive electrode is rotated steadily at about 16 r.p.m. during operation but the negative is not ordinarily rotated. After a few minutes burning, the salt-laden core of the positive has burned some 7 or 8 mm. below the end of the shell and the inner part of the shell itself has burned out forming a crater 14 mm. across and having the general outline of a truncated cone with the end of the core forming the truncated surface. This crater is uniform in size and form throughout the life of the electrode and the rotation of the electrode makes the burning rate uniform around the shell and preserves the symmetry of the crater rim. This latter feature is vital to the successful operation of the arc, for a stop of a half minute in the rotation has a generally disastrous effect.

The current density in the positive is quite high and the electrode is white hot from the crater back to the brush or electrical contact. This high temperature drives off the fluorides in the form of gas, and this gas fills the crater and acts as a conductor for the current. The passage of the current through the gas heats it to a temperature that, judging from the distribution of energy in the visible spectrum seems to be in excess of 5500 deg. A. The gas within the crater has a brilliancy of 700 cd. per sq. mm. at the point of greatest crater depth, and as the gas is transparent the crater walls add some 135 cd. per sq. mm. giving a total brilliancy of about 835 cd. per sq. mm. of projected area or over six times the best brilliancy of pure carbon.

There is visible in the center of the crater a spiral or annular column of gas of greater brilliancy than the surrounding gas. This core of gas at its point of greatest depth gives the high value of 700 candles per sq. mm., and at the sides of the crater where the depth is less the brilliancy is lower, finally reaching the brilliancy of carbon alone at the crater rim. In addition to the variation between center and rim there is a second variation between top and bottom due to the strong tendency of the hot gases to rise and flow out over the upper edge of the crater. This tendency can be combated by setting the negative so that the high velocity gas from the tip of the negative strikes against the upper half of the crater and thus dams up the light-giving gas and increases the volume held in the crater.

The luminous gas after escaping from the crater forms a flame of great brilliancy that gives off almost half as much light as the crater itself. It is largely due to this flame that the high-intensity arc cannot be investigated through the medium of either the idealized disk or the spherical source. The photographs in Figs. 104 to 107 give an idea of the distribution of light in and around the crater, but there is proportionally more blue light in the lower part of the flame than in the crater and the camera therefore gives undue value to the flame light. The flame intensity at the point where it escapes from the upper edge of the crater is nevertheless sufficiently high to give the beam an oval section; the prolonged point due to the upstanding flame is pointed downward in the beam, and therefore the vertical diameter between the ten per cent points is considerably greater than in the horizontal direction.

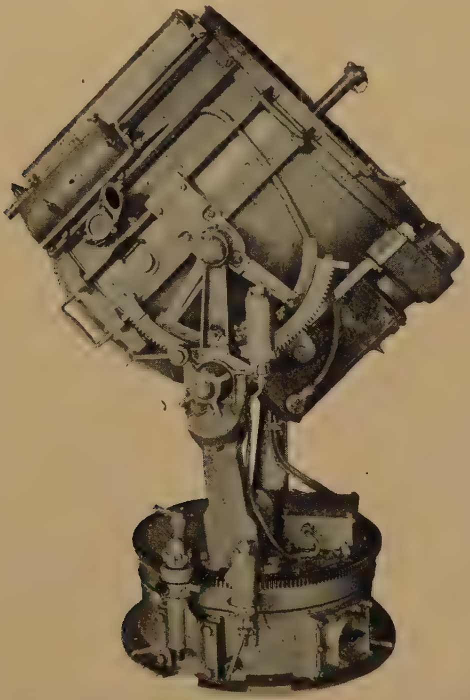


Fig. 97. This 24-in. Type of High-intensity Searchlight is Especially Designed for Sea Service and has Operated Quite Successfully on Destroyers where the Vibration is Severe and the Flying Spray Amounts to a Permanent Salt Bath. The current is 75 amp. and the lamp is constructed to maintain this current at a constant value by regulating the arc length

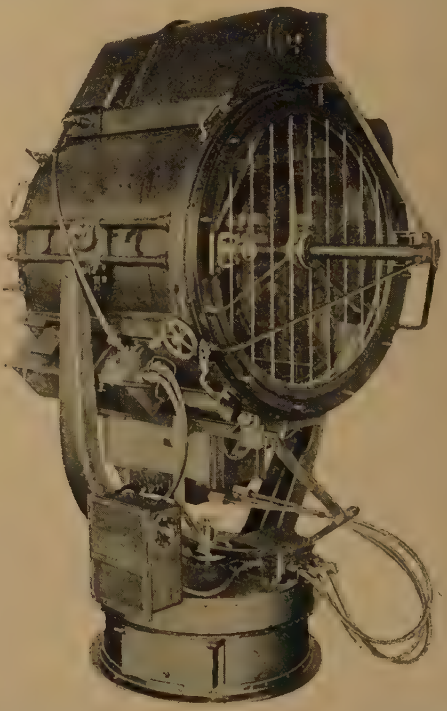


Fig. 98. This 30-in. Type of High-intensity Searchlight Differs from those shown in Figs. 97, 99, and 100 by Having a Vacuum System of Ventilation, the Inlet for which is at the Back of the Searchlight. The current is 120 amp. and the automatic mechanism includes means for maintaining the crater at the focal point of the mirror under all conditions

General Data on 60-in. High-intensity Searchlight

In the following computations and curves on the high-intensity arc, the specific case of a 60-in. high-intensity searchlight will be largely used. This particular size of searchlight has been employed in a large number of photometric, spectrophotometric, and visibility tests and more is known about its characteristics than any other type or size.

The barrel type of searchlight is used, and allowances are made for a number of minor factors that might, if neglected, add to a considerable item. Thus a factor of 0.850 is used for the reflectivity of the mirror whereas a good mirror reflects 0.865, and the difference will cover the loss due to dirt or smoke on the surface of the glass. Ten per cent is allowed for the loss in the glass door that closes the front of the searchlight. The negative head casts a shadow near the center of the mirror, and to compensate for this lost area, the 10-deg. or central zone is dropped from the computations. Also the narrow zone beyond 60 deg. is not included and this omission alone should provide a good margin of safety for the computed intensities.

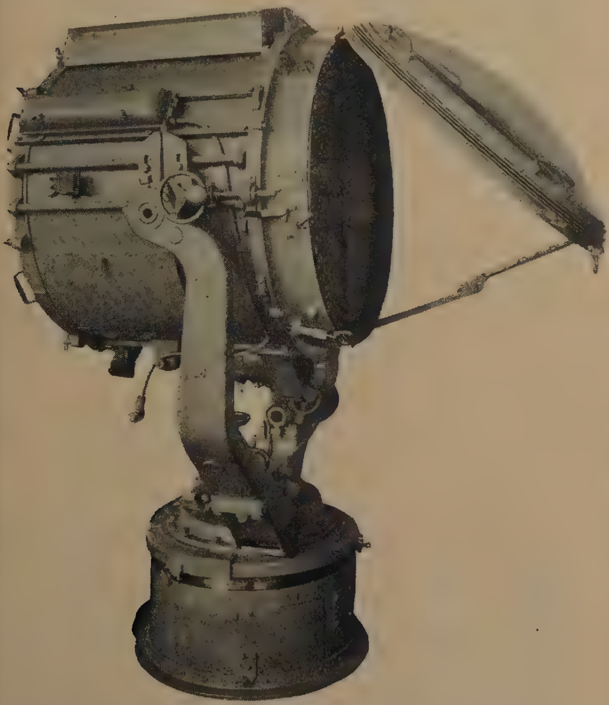


Fig. 99. This 36-in. Fully Automatic Searchlight of the High-intensity Type takes a Constant Current of 150 amp. In addition to the usual night service it is also used for signal service during the day, using the Venetian shutter for sending Morse code. The dome door in the front may be swung open for inspection and cleaning, but access is obtained to the lamp and mirror by a large door in the side of the drum or by removing the mirror with its mounting

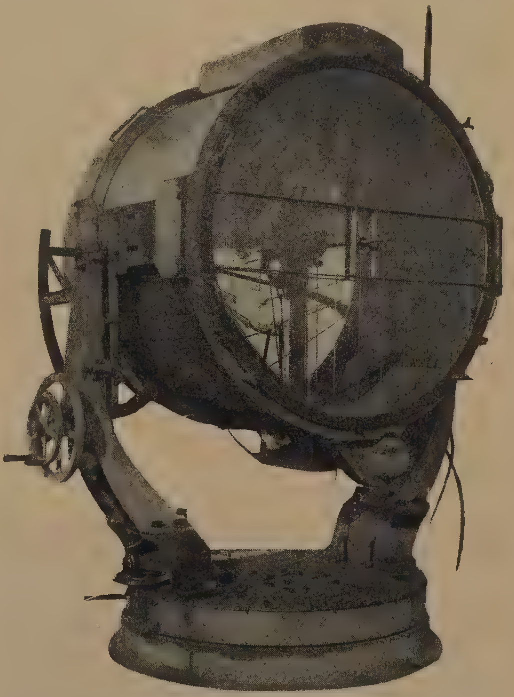


Fig. 100. This 60-in. High-intensity Searchlight is Designed for Coast Fortifications or Other Permanent Locations. The ventilation is of the plenum type and the motor for the fan and lamp mechanism is attached to the front of the searchlight. The ventilation is such that practically no smoke will be deposited on either mirror or door even if the searchlight is depressed 30 deg. or elevated to beyond the vertical. In spite of the heavy construction, the searchlight may be readily rotated and elevated by one man, or if desired, remote electric control may be used. The current is 150 amp.

Crater Analysis

The unsymmetrical distribution of light from the rising gas of the high-intensity crater makes it necessary to depart from the usual test methods of crater brilliancy analysis. In Fig. 110 is shown an analyzing disk that transmits light in ten concentric zones of equal area. The circular openings in the disk have areas of 1, 2, 3, ... 10, and nine plugs were made to fit the openings 1, 2, 3, ... 9. These plugs are shown mounted in the center of openings 2, 3, 4, ... 10, so that between the outer edge of the plug and the inner edge of the opening there is an annular opening of area 1 in every case.

A projection lens was placed in front of the arc so as to collect the light at any desired angle from the axis. This lens formed an image of the complete arc in the plane of the disk and by bringing the disk openings in succession into the image the light from successive zones in the crater was transmitted through to the photometric integrator.

It has been mentioned several times in discussing the origin of useful light that the boundaries of useful origin are always circular and of constant solid angle as measured from points on the mirror. The analysis was therefore made with circular zones which included light from within the dotted circles drawn on Figs. 104 to 107.

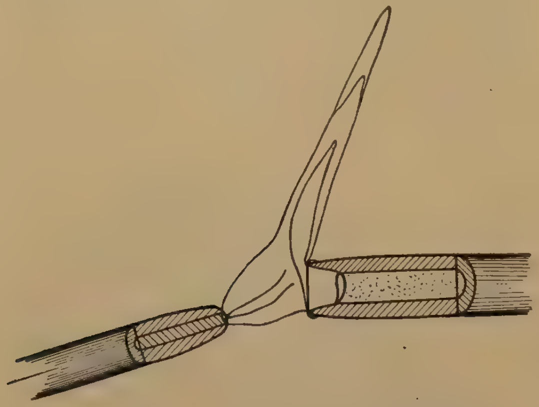


Fig. 101. Diagram of the High-intensity Arc. The ends of the electrodes are cut away to show the form taken by the electrodes when burning. The crater is filled with luminous gas, which upon escaping from the top of the crater is driven upward in a slanting direction by the impact of the gas from the negative electrode

The photometric test included a determination of the *total* light in all directions within 60 deg. of the axis and the *useful* radiation within the same region. It was found that 62.6 per cent of the total radiation was useful and 37.4 per cent was reflected outside of the beam boundaries. The photometric curves of Fig. 111 show how the arc radiates useful and waste light.

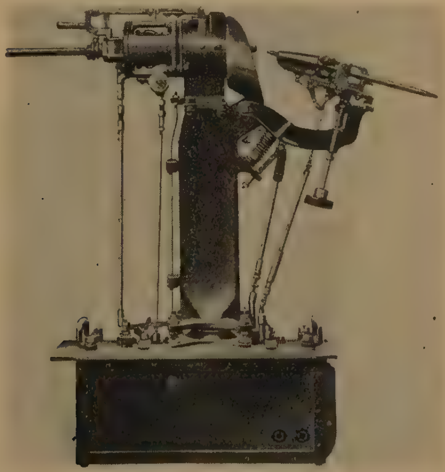


Fig. 102. Mechanism of the 24-in. Automatic High-intensity Lamp showing the Electrodes Held in the Burning Position. The positive electrode is rotated and fed forward to keep the crater at the focal point. The negative electrode is not rotated but is moved forward or backward to keep the current constant at 75 amp.

The crater brilliancies in the various concentric zones are given by the curves of Fig. 112. The central brilliancy from almost any angle of view is 850 cd. per sq. mm. but the average brilliancy for a given radius about the center of the crater naturally decreases as the angle of view moves from the axis and as the circle of useful radiation includes a greater and greater portion of the outside of the crater and the relatively dim arc stream.

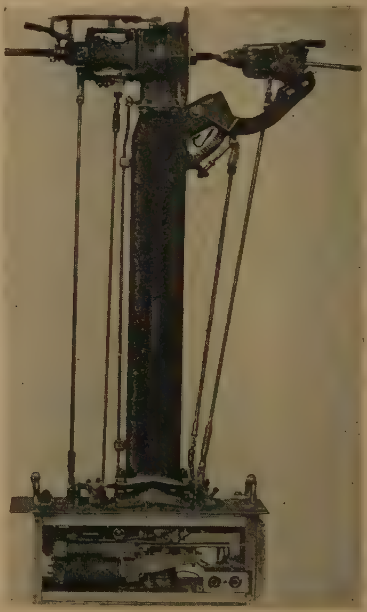


Fig. 103. Mechanism of the 60-in. Automatic High-intensity Lamp showing the Negative Head Swung up to Bring the Carbons into Contact and thus Start the Arc. The current through the arc passes through the coil shown in the base of the lamp, drawing in the armature and pulling the negative head down into the burning position. The same coil operates a relay to keep the current constant

Graphical Determination of Beam

The construction of the beam characteristic curve from the zonal images follows closely the method used for the spherical source of uniform surface brilliancy. The brilliancy curves of Fig. 112 when raised to a value proportional to the mirror brilliancy times the zonal area represent the intensity of the zonal images; the widths of the images are

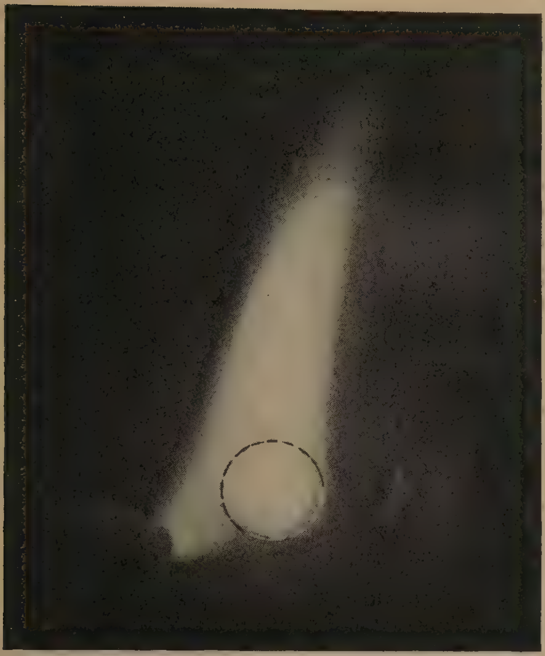


Fig. 104. Appearance of 150-amp. Arc from 30-deg. Point on Mirror

The various steps of photographing and reproducing distort the intensities of the various parts and give the flame above the crater an undue brightness. The dotted circle is drawn around the crater to outline the region of useful light which is determined by the angular diameter of the crater as viewed from the center of the mirror

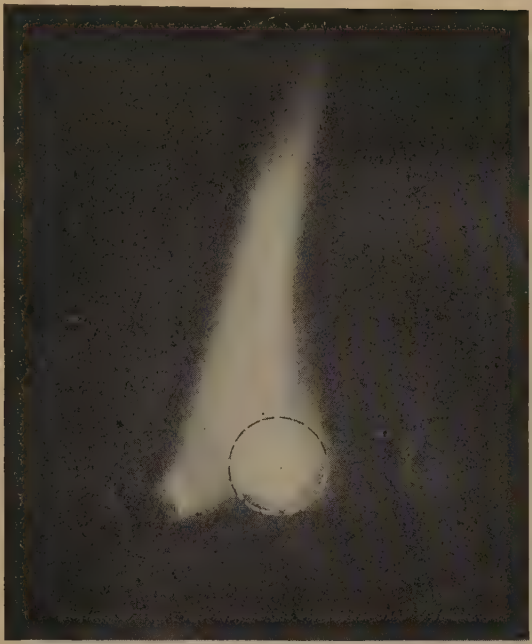


Fig. 105. Appearance of Arc from 40-deg. Point on Mirror

The comparative darkness of the carbon crater wall as compared with the luminous gas illustrates how greatly superior the latter is in brilliancy

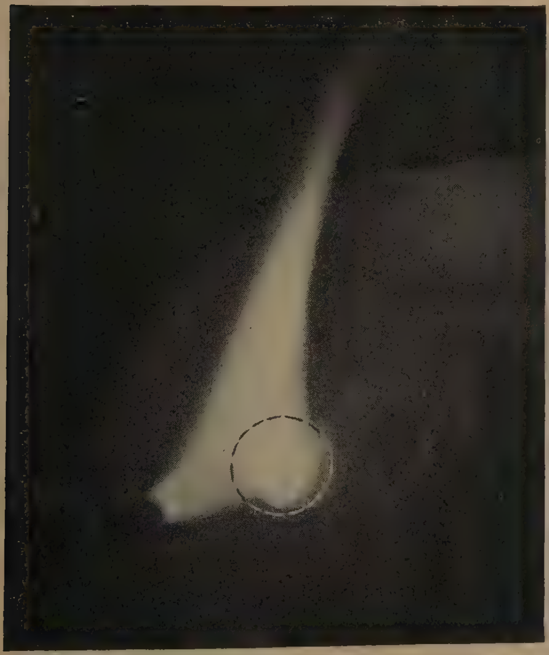


Fig. 106. Appearance of Arc from 50-deg. Point on Mirror

The crater as viewed from this point occupies only a small percentage of the circle of useful radiation, and considerable flame light is included in the beam proper. The backward tilt of the flame position, due to the impact velocity of the negative gas, is becoming more evident

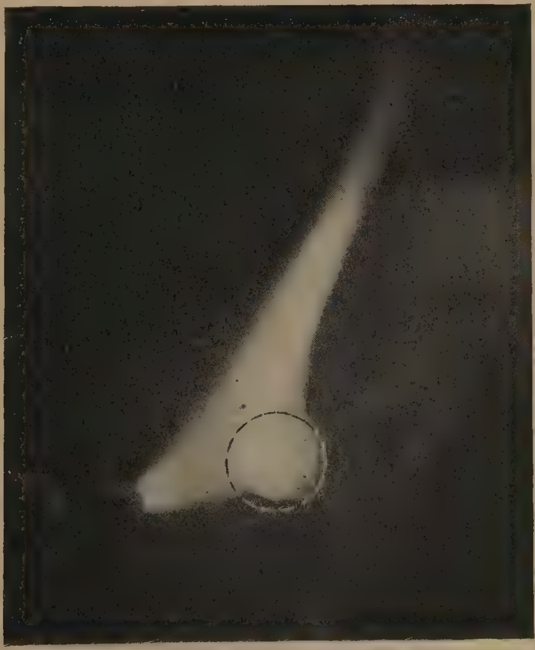


Fig. 107. Appearance of Arc from 60-deg. Point on Mirror

The circle of useful radiation here includes a considerable area of the sides of the positive electrode and of the violet colored arc flame proper between electrodes. This added light is nearly all reflected into the borders of the beam and its strong color characteristic has an important bearing on both the progressive diminution of angular width at increasing distance and the visibility of targets drawn to either an angular scale or a linear scale for some predetermined test distance, and are readily determined from the length of the radius vectors to the centers of the zones. This computation in no wise varies from that for the spherical source, but the zonal images are triangular in general outline instead of rectangular. The summation of zonal images from 10 to 60 deg. gives the characteristic curve of Fig. 113 which has a central intensity of 1,096,500,000 cd.

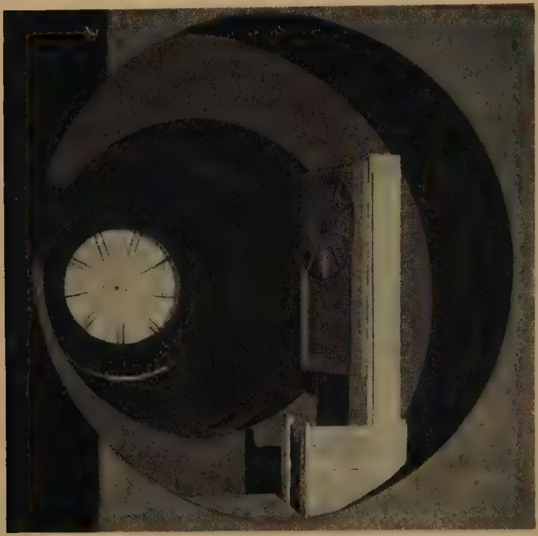


Fig. 108. The Hemispherical Photometric Integrator Collecting Light Directly from the Arc. This arrangement allows a measurement of all light from the crater and flame in a given direction regardless of its origin in the arc

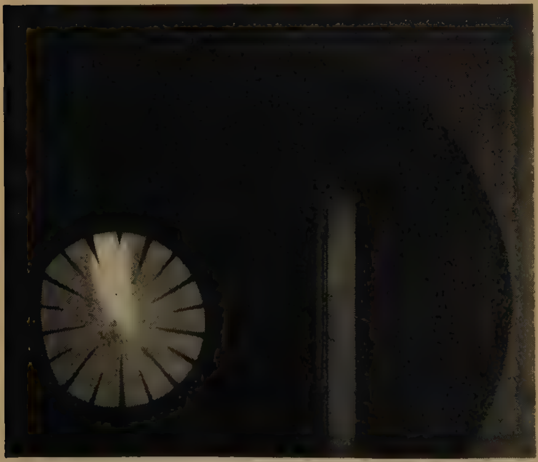


Fig. 109. The Second Step in the Analysis of Crater Brilliancy is the Collecting of the Light by a Lens Placed in the Line of the Light Previously Measured. The image is formed in the plane of the disk in the foreground, which is swung aside to allow the light to pass in its entirety into the integrator

It was this computation of central intensity that led to a general review of the theory of the searchlight to account if possible for the greatly reduced intensity found by actual test. The best results by test were of the order of 700,000,000 cd. and of the remaining 400,000,000 we can now rather definitely ascribe to certain defects in the mirror which will be discussed in detail later.

The ways in which the construction of the high-intensity beam characteristic varies from the similar construction for the spherical source characteristic are brought out most clearly when dealing with the beam at short range. In Figs. 114 to 118 the zonal images are worked out for a test range of 610 ft., and in Fig. 118 the construction lines are given so that the method can be followed more easily.

The axis of the elemental image is separated from the axis of the mirror by the radius of the 55-deg. point which is 677 mm. The central height of the elemental images is the central brilliancy of the crater times the area of the 50 to 60-deg. zone times the coefficient of the mirror times the coefficient of the door.

$$I_{50\text{-}60} = 825 \times 614{,}000 \times 0.85 \times 0.90$$
$$= 387{,}000{,}000 \text{ cd.}$$

The width of the image is the width of the source to some selected point on the crater rim times the ratio of the test range to the radius vector from the focus to the 55-deg. zone.

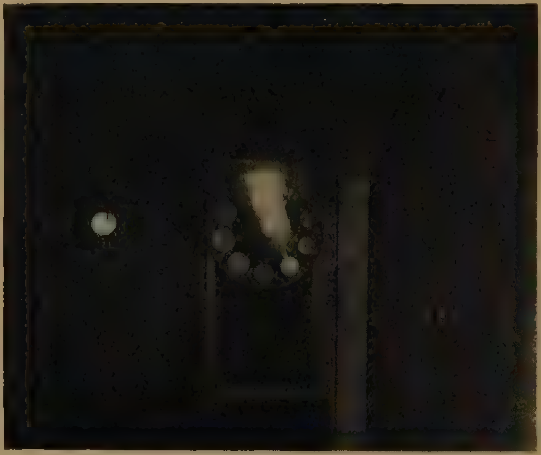


Fig. 110. The Image of Crater and Flame are Visible on the Upper Part of the Analyzing Disk. The dark ring about the center of the crater is an annular opening that passes light into the integrator beyond for measurement

In Fig. 118 the points of 0.9, 0.8, etc., central intensity are marked on the elemental image, and perpendiculars are dropped from these points to the base line. Using the axis of the image as a center, concentric circles are drawn through the foot of each perpendicular and these circles represent lines of equal intensity. In the actual case, the equal intensity curves are egg shaped with the point downward. But the test method of obtaining the crater brilliancy gives the average values for concentric zones, and we must therefore use these average values for the entire circumference of each zone.

There are of course an infinite number of elemental images arranged around the axis of the beam but for the purpose of the graphical construction we can deal with only one, and consider that all the light of the mirror zone is concentrated in this single image.

In Fig. 118 the axis of the beam is made the center of concentric dotted circles spaced 0 deg. 5 min. apart. These circles are marked *a*, *b*, *c*, ... *k*, and eleven radial lines *A*, *B*, *C*, ... *K* divide the half section of the beam into ten equal parts. Let us call these circles *beam* circles and the ones about the axis of the elemental image *intensity* circles. On the axis of the beam, the intensity is 0.54 when read for the position between the two adjacent intensity circles. The *b* beam circle crosses the 0.3, 0.4, 0.5 and

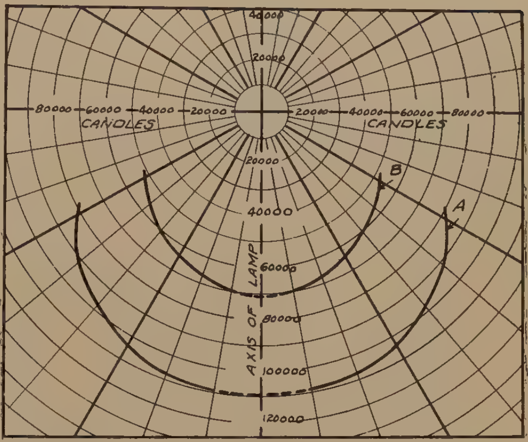


Fig. 111. Curve *A* Gives the Total Intensity from all Parts of the Arc While Curve *B* Gives that Part of the Light that Will be Reflected to Within the Beam Boundaries. At angles far removed from the lamp axis the latter light greatly exceeds the true crater light and an analysis of the latter alone would not give data for the computation of the beam

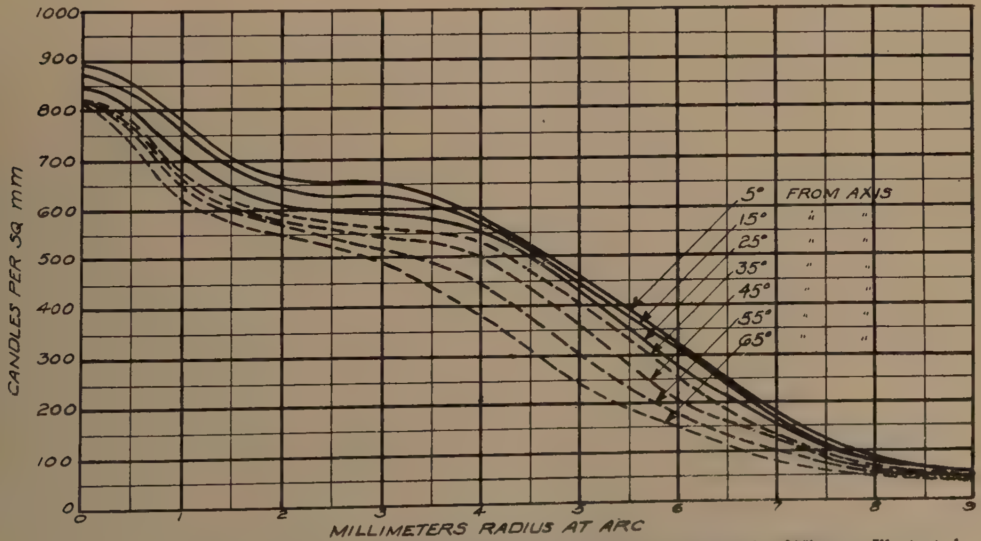


Fig. 112. The Brilliancy of Even the Center of the Crater is Influenced by the Angle of View, as Illustrated by these Curves where the 5-deg. Position shows a Central Intensity of 890 cd. per sq. mm. while the 65-deg. Position shows only 820 cd. per sq. mm. These curves were obtained with the aid of the analyzing disk shown in Fig. 110

TABLE V

GENERAL DATA ON 60-IN. HIGH-INTENSITY SEARCHLIGHT

Current through arc	150 amp.
Line voltage	110 volts
Arc voltage	78 volts
Mirror diameter (effective)	1524 mm.
Focal length (to back surface)	650 mm.
Mirror angle (from axis)	60 deg. 44 min.
Coefficient of reflection of mirror	0.85
Coefficient of transmission of door	0.90
Shadow of negative head covers	10 deg. from axis
Positive electrode shell	16 mm. dia.
Positive electrode core (impregnated)	8 mm. dia.
Negative electrode shell	11 mm. dia.
Negative electrode core (soft)	3 mm. dia.
Positive electrode rotated	16 r.p.m.

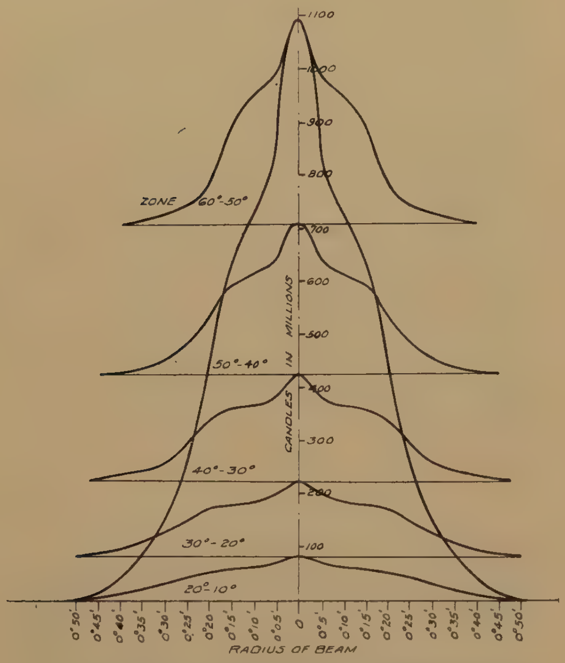


Fig. 113. The Beam Characteristic of a High-intensity Arc in a 60-deg. Mirror Greatly Resembles in Form the Curves of Crater Brilliancy, with some Smoothing out Due to the Varying Image Enlargement of the Different Mirror Zones. The absence of a square top or crest is noticeable and the long taper at the foot of the curve is seen in the actual beam as a hazy and indefinite edge. The mirror zone from 0 to 10 deg. is omitted to compensate for the shadows of the negative head, and the narrow active zone on the mirror beyond 60 deg. is omitted to take care of certain unavoidable depreciation losses that cannot well be exactly evaluated

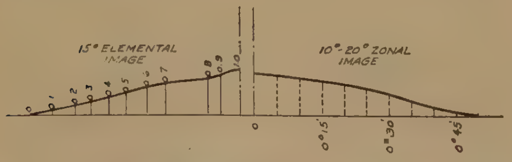


Fig. 114. The Zonal Beam at 610 ft. (right-hand side) is Derived from the Elemental Image from the 10 to 20-deg. zone (left-hand side) and the Non-coincidence of the Axes of the Elemental Beams with the Axis of the Entire Beam Results in a Slight Widening and Weakening of the Resultant Image or Beam

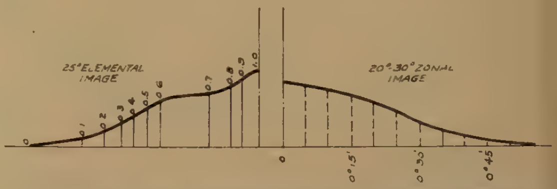


Fig. 115. The Change in Shape Between the Single Elemental Image and the Zonal Image is more Pronounced as the Separation of their Axes, the y-distance on the Mirror, Becomes Greater

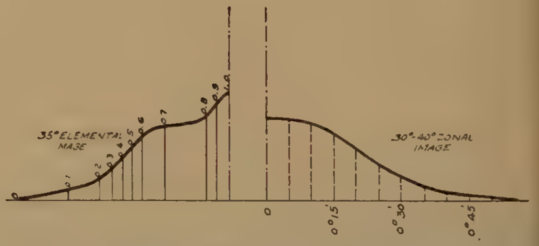


Fig. 116. The Zonal Image here Bears Small Resemblance to the Elemental Image and the Great Loss of Central Beam Intensity is Due to the Elemental Peaks of Intensity Falling so Far to One Side of the Beam Axis

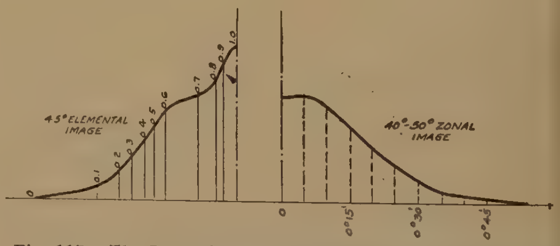


Fig. 117. The Loss of Central Intensity Here Amounts to 30 Per Cent and the Faint Sign of the Zonal Beam Becoming Annular is Traceable to the Concave Section Near the Axis of the Elemental Beam

TABLE VI

DATA FOR COMPUTATION OF ZONAL IMAGES FOR 60-IN. HIGH-INTENSITY SEARCHLIGHT

ZONE				Maximum Crater Brilliancy	Maximum Zone Candles	Radius of Mid. Zone
Mid.	From	To	Sq. mm.			
6°40′	0°	10°	40,600	890 cd. per sq. mm.²	27,600,000	76 mm.
15°	10°	20°	124,600	870 cd. per sq. mm.²	83,000,000	171
25°	20°	30°	216,300	850 cd. per sq. mm.²	140,500,000	288
35°	30°	40°	322,000	825 cd. per sq. mm.²	203,000,000	410
45°	40°	50°	449,000	825 cd. per sq. mm.²	283,000,000	539
55°	50°	60°	614,000	825 cd. per sq. mm.²	387,000,000	677
Total for Mirror 0°–60°					1,124,100,000 candles	
Total for Mirror 10°–60°					1,096,500,000 candles	

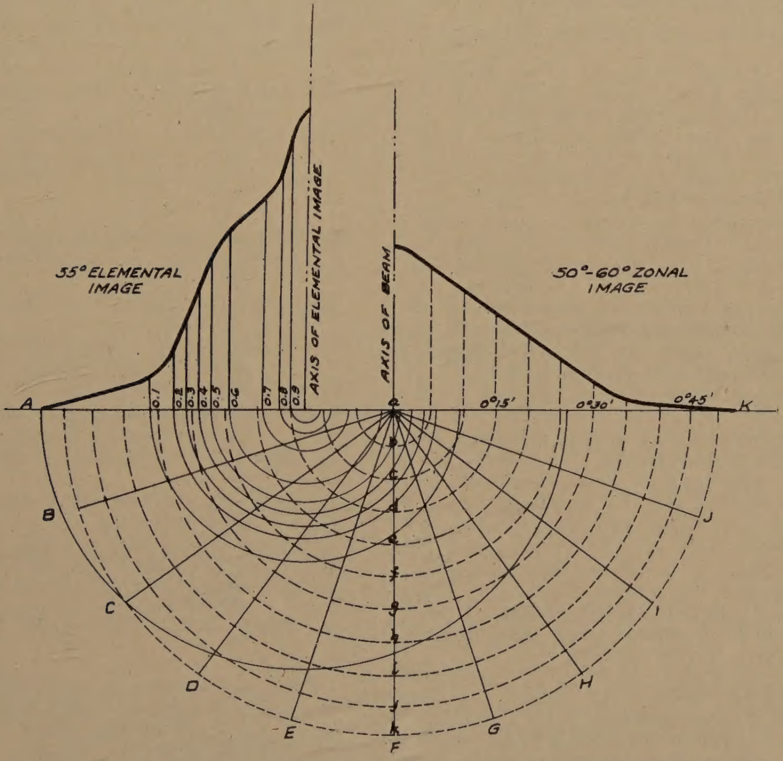


Fig. 118. The circles concentric about the foot of the axis of the elemental image are lines of equal intensity while the dotted circles about the foot of the beam axis are lines of equal angular displacement

0.6 intensity curves, and we may obtain the real average intensity around this beam circle by noting the intensities at the intersections of the *b* circles and the radials *A*, *B*, *C*, ... *K*. In finding this average the *A* reading and the *K* reading are divided by two and the nine intermediates *B*, *C*, ... *J* are put down as read. The average so obtained, 0.47, is plotted on a perpendicular 0 deg. 5 min. to the right of the beam axis and is a point on the desired zonal image.

(To be Continued)

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Arc Welding

Fluxes and Their Functions in Electric Arc Welding. Caldwell, J.
Am. Weld. Soc. Jour., Dec., 1923; v. 2, pp. 27-32.

Welded Rail Bonds. Febrey, H. H.
Am. Weld. Soc. Jour., Dec., 1923; v. 2, pp. 18-24.
(Pertains chiefly to arc welding methods.)

Brushes, Electric

Brush Mounting as a Factor of Satisfactory Operation. Jones, Philip Chapin.
A.I.E.E. Jour., Dec., 1923; v. 42, pp. 1318-1321.

Carrier-current Communication

Recent Developments in Carrier-current Communication. Fuller, Leonard F.
A.I.E.E. Jour., Dec., 1923; v. 42, pp. 1271-1274.
("Discusses several recent developments in apparatus and methods of operation.")

Some Experiences with a 202-Mile Carrier-current Telephone. Crellin, E. A.
A.I.E.E. Jour., Dec., 1923; v. 42, pp. 1275-1277.
(Short account of the system between the Pit River Power House No. 1 and Vaca-Dixon substation, on the lines of the Pacific Gas and Electric Company.)

Corrosion

Removal of Rust by Electrolytic Processes. McLare, J. P.
Engng., Jan. 4, 1924; v. 117, pp. 25-29.
(Method used by the British Government in salvaging war materials.)

Current-collecting Devices

Under-contact Conductor Rails.
Elec'n, Jan. 4, 1924; v. 92, pp. 10-11.
("A new design giving complete protection for high tension traction.")

Electric Furnaces

Electric Furnace Refractories. Gosrow, R. C.
Chem. & Met. Engng., Dec. 31, 1923; v. 29, pp. 1181-1185.
("Practical suggestions for the construction of lining walls, hearths and roofs.")

Electric Heating

Ford Factory Heated Electrically.
Power, Jan. 8, 1924; v. 59, pp. 57-58.
(Short account of an installation in the Green Island, N. Y., plant. The system uses electrically heated hot water.)

Electric Transmission Lines

Modern High-tension Power Transmission Lines. Dreyer, Walter.
Engng. News-Rec., Jan. 3, 1924; v. 92, pp. 8-10.
(On the essentials of design of towers and lines. Author is Assistant Civil Engineer, Pacific Gas & Electric Company.)

Electric Transmission Lines, Artificial

Artificial Transmission Lines with Distributed Constants. Dellenbaugh, Jr., F. S.
A.I.E.E. Jour., Dec., 1923; v. 42, pp. 1293-1296.
(Describes construction and use of such lines. Bibliography of eight entries. Abridgement. Discussion, pp. 1343-1347.

Electricity—Applications—Agriculture

Electric Drive in Agriculture. Mattheka, F. (In German.)
Bergmann Mit., Nov.-Dec., 1923; v. 1, pp. 127-139.
(Illustrated description of various motor applications; also tables of power consumptions, etc.)

First Experimental Rural Line Just Completed in Minnesota. Stuart, Charles F.
Elec. Lt. & Pr., Jan., 1924; v. 2, pp. 60, 62, 64-65.
(Short account of a line near Red Wing, Minnesota.)

Electricity—Applications—Boiler Plants

Electrical System of Combustion Control for Boiler Plants.
Power, Jan. 8, 1924; v. 59, pp. 46-48.

Heat

Free and Forced Convection of Heat in Gases and Liquids. Rice, Chester W.
A.I.E.E. Jour., Dec., 1923; v. 42, pp. 1289-1293.
(Mathematical study, giving results of tests. Abridgement, with discussion.)

Insulation—Testing

Influence of Gaseous Ionization and Spark Discharge on Fibrous Insulating Materials and on Mica. Whitehead, J. B.
A.I.E.E. Jour., Dec., 1923; v. 42, pp. 1297-1304.
(Includes bibliography of nine entries.)

Insulators—Testing

Test Results on the Performance of Suspension Insulators in Service. Benham, C. F.
A.I.E.E. Jour., Dec., 1923; v. 42, pp. 1257-1258.
(Results of megger tests on insulators of the Great Western Power Co.)

Hydro-electric Development

Fundamental Problems of Hydro-electric Development. Freeman, John R.
Mech. Engng., Jan., 1924; v. 46, pp. 1-12, 39.
(Discusses the fundamentals of hydro-electric development, particularly its economic aspects.)

Lightning Arresters

High-voltage Switches, Bushings, Lightning Arresters; Experiences of the Southern California Edison Company on its 60,000-, 150,000- and 220,000-volt System. Michener, Harold.
A.I.E.E. Jour., Dec., 1923; v. 42, pp. 1251-1254.

Lubrication and Lubricants

Steam Power Plant Prime Movers and Their Lubrication.
Lubrication, Nov., 1923; v. 9, pp. 121-132.
(Treats of steam engine and steam turbine lubrication.)

Metal Coating

Use of Aluminum to Prevent Steel Corrosion. Farr, Arthur V.
Chem. & Met. Engng., Dec. 31, 1923; v. 29, pp. 1188-1189.
(Short description of the calorizing process.)

Power-factor

Economic Considerations of the Power-factor Control of Long High-voltage Lines. Joslin, A. V.
A.I.E.E. Jour., Dec., 1923; v. 42, pp. 1248-1250.

Railroads—Electrification

Electric Railways in Italy.
Elec. Rev., Dec. 28, 1923; v. 93, pp. 964-967.
(Describes the progress which has been made in electrification in Italy.)

Resistors

General Formula for Calculating the Temperature of Electrically Heated Wires.
Elec. Rev., Dec. 28, 1923; v. 93, pp. 989-990.
(Data for the design of heating elements. Includes table of physical constants of resistance materials bearing various trade names.)

Standards

Example of Standardization in German Industry.
Mech. Engng., Jan., 1924; v. 46, pp. 54-55.
("D. I. N." standards for manufacturing processes, as used by Siemens & Halske, Berlin.)

Standardization Means Economy. Whitney, Albert W.
Elec. Wld., Jan. 5, 1924; v. 83, pp. 33-35.
(An outline of the results accomplished by the American Engineering Standards Committee.)

Steam Plants

High Pressures and High Superheats in Modern Steam-power-plant Practice. Noack, G.W.
Mech. Engng., Jan., 1924; v. 46, pp. 40-42.
(Translated from the German of a Brown, Boveri & Cie. publication of 19 pages, dated June, 1923.)

Street Lighting

Eleven Solutions of a Street Lighting Problem.
Illum. Engng. Soc. Trans., Dec., 1923; v. 18, pp. 885-937.
(Results of a questionnaire in the form of a street lighting problem, solutions for which were received from eleven different sources.)

Pageant Street Lighting. Hibben, Samuel G.
Illum. Engng. Soc. Trans., Dec., 1923; v. 18, pp. 938-948.

Vibrations

Influence of Foundation Vibrations on the Operation of Turbine-generators. Pape, W. (In German.)
Bergmann Mit., Nov.-Dec., 1923; v. 1, pp. 148-160.
(Tells of experiments and observations on the causes and effects of vibrations.)

Water Power

Chicago's Diversion of Water from the Great Lakes.
Engng. News-Rec., Jan. 3, 1924; v. 92, pp. 28-31.
(A condensed history of the case. Includes reference to the effect on Niagara Falls power plants.)

X-Rays

Absolute, Direct-reading Dosimeter for Deeply-Penetrating X-Rays. Dauvilier, A. (In French.)
Revue Gén. de l'Elec., Dec. 8, 1923; v. 14, pp. 887-902.
(Describes a new device for accurate control of therapeutic applications of X-rays and of the gamma rays of radium.)

NEW BOOKS

Car Lighting by Electricity. Stuart, Charles W. 356 pp., 1923, N. Y., Simmons-Boardman Pub. Co.

Der Funkentelegraphische Wetter und Zeitzeichendienst. Thurn, H. 82 pp., 1923, Berlin, M. Krayn.

Design of Diagrams for Engineering Formulas and the Theory of Nomography. Hewes, Lawrence I., and Seward, Herbert L. 111 pp., 1923, N. Y., McGraw-Hill Book Co., Inc.

Electricity and its Applications to Automotive Vehicles. Stone, Paul M. 844 pp., 1923, N. Y., D. Van Nostrand Co.

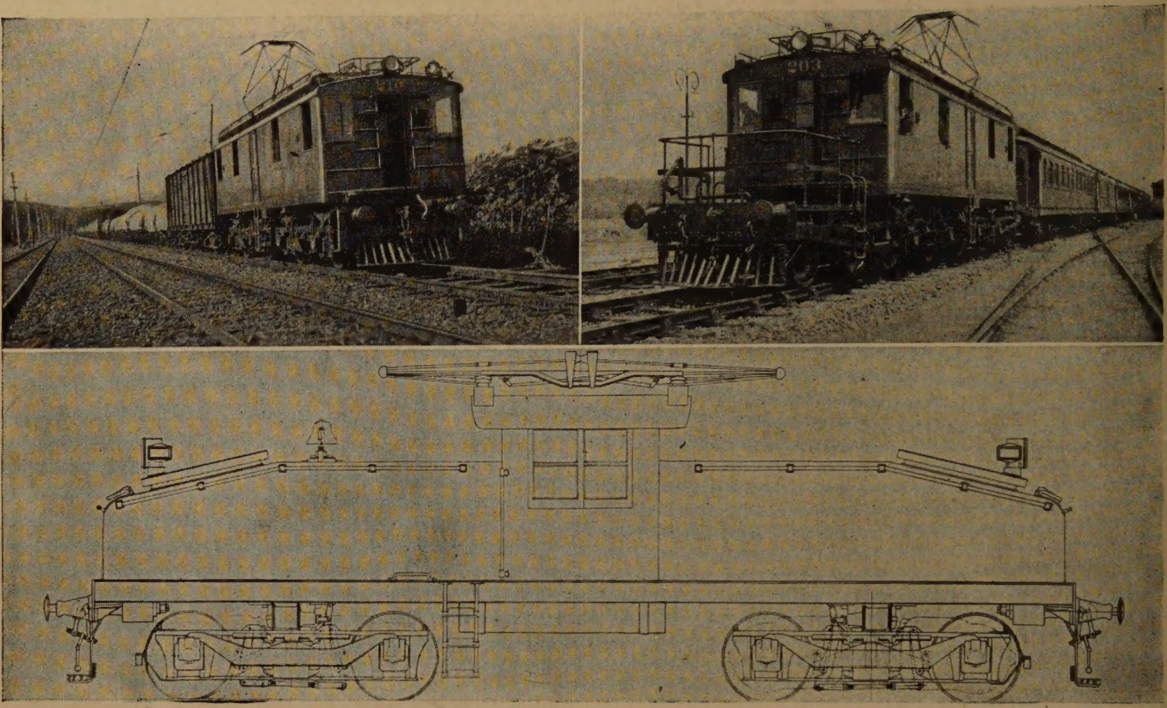
Handbook of Industrial Oil Engineering. Ed. 2. Battle, John Rome, 1141 pp., 1923, Phila., J. B. Lippincott Co.

Hydroelectric Power Stations, Ed. 2. Rushmore, David B., and Lof, Eric A. 830 pp., 1923, N. Y., John Wiley & Sons.

Treatise on Electro-Metallurgy. Ed. 4, rev. & enl. McMillan, Walter G. 449 pp., 1923, Phila., J. B. Lippincott Co.

Vector Analysis. Runge, C. 226 pp., 1923, N. Y., E. P. Dutton & Co.

For the Paulista in Brazil



Views of present main line locomotives and outline of new 60-ton switcher

5 New 60-ton Electrics Ordered

Two years of successful operation of a dozen electric locomotives on the Paulista Railway is responsible for a repeat order for five 3,000-volt, direct-current units of practically the same type. These locomotives are to be used in switching yards at various points in the electric zone.

Scarcity and high price of coal was a principal factor compelling the Paulista electrification. Furthermore, traffic was heavy and the grades are steep.

The operation of the section already electrified has accomplished substantial savings. With the electrification of the extension contemplated, it is expected to haul with ease more than double the tonnage formerly handled.

(Paulista)
Santa Fe's
buffer x coupler jack
system) eliminated
in early
1980s.

ally these
units renumbered
collisions and
were converted
to
switchers
replaced
in 1980s

General Electric Company
Schenectady, N. Y.

American Locomotive Company
New York, N. Y.

AMERICAN LOCOMOTIVE COMPANY
GENERAL ELECTRIC COMPANY

Say you saw it advertised in the General Electric Review